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HOLDING THE EDGE

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Maintaining the Defense Technology Base

CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

Technological superiority has been a cornerstone of United States security and industry since World War II. That cornerstone is not crumbling, but over the past decade it has weathered significantly. Foreign companies have made deep inroads into high-technology markets that had been more or less the exclusive domain of U.S. industry. In addition to causing economic problems, this has fostered dependence on foreign sources for defense equipment at a time when the technology in defense systems comes increasingly from the civilian sector. At the same time, the Department of Defense reports that Soviet defense technology is catching up with ours, and sophisticated Western military equipment is routinely sold to third world nations.

These trends—and others—have prompted the Senate Committee on Armed Services to ask what needs to be done to maintain the base of high technology on which U.S. national security depends. This report, the second of OTA's assessment "Maintaining the Defense Technology Base," looks into that question in some depth. An earlier report, *The Defense Technology Base: Introduction and Overview* (OTA-ISC-374, March 1988), provided a broad view of the defense technology base and the concerns regarding its health.

This report develops some of the ideas introduced in the first report. It examines the management of DoD technology base programs and laboratories. It also analyzes the process through which technology is introduced into defense systems, in order to understand why it takes so long and what might be done to speed the process up. Finally, this report examines the exploitation of civilian commercial sector technology for defense needs. It concentrates on the dual questions of expediting military access to civilian technology and keeping the necessary base of technology alive and well in the United States. Volume 2 of this report contains extensive appendices and will be published in the summer of 1989.

The help and cooperation of the Army, Navy, Air Force, the Office of the Secretary of Defense, the Department of Energy, NASA, and the National Institute of Standards and Technology are gratefully acknowledged.

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Acronyms

AAAS	—American Association for the Advancement of Science
AATR	—Aided Automatic Target Recognition
AEC	—Atomic Energy Commission
AMC	—Army Materiel Command
ANSI	—American National Standards Institute
APL	—Applied Physics Laboratory
ASD	—Aeronautical Systems Division (Air Force Systems Command)
AT&T	—American Telephone and Telegraph
ATD	—Advanced Technology Demonstration
ATR	—Automatic Target Recognition
ATTD	—Advanced Technology Transition Demonstration
BTI	—Balanced Technology Initiative
CDP	—Chief of Defense Procurement (U.K.)
CERN	—Controller, Establishments, Research, and Nuclear
CEST	—Centre for the Exploitation of Science and Technology
CINCs	—Commanders in Chief (of Unified and Special Commands)
COBOL	—Common Business-oriented (programming) Language
COCO	—contractor-owned, contractor-operated
COE	—Corps of Engineers
COTS	—Commercial Off-the-Shelf
CSIS	—Center for Strategic and International Studies
D-RAM	—dynamic random access memory
DARPA	—Defense Advanced Research Projects Agency
DCS(T&P)	—Deputy Chief of Staff for Technology and Plans
DCSPER	—Deputy Chief of Staff for Personnel
DDDR&E(R&AT)	—Deputy Director of Defense Research and Engineering for Research and Advanced Technology
DDR&E	—Director of Defense Research and Engineering
DFG	—German Research Society
DG	—Defense Guidance
DGA	—Delegation Generale pour l'Armement (France)
DoD	—Department of Defense
DOE	—Department of Energy
DRB	—Defense Resources Board
DSB	—Defense Science Board
EC	—European Community
EN	—Engineering Directorate (of ASD)
FAR	—Federal Acquisitions Regulations
FOG-M	—Fiber Optic Guided Missile
FSX	—Fighter Support Experimental
GAO	—General Accounting Office
GNP	—gross national product
GOCO	—government-owned, contractor-operated
GS	—General Schedule
IDA	—Institute for Defense Analyses
IEPG	—Independent European Program Group
ILIR	—In-house Independent Laboratory Research
IRST	—Infrared Search and Track
ISDN	—Integrated Services Digital Network
ISO	—International Standards Organization
ISTO	—Innovative Science and Technology Office
ITT	—International Telephone and Telegraph
JCS	—Joint Chiefs of Staff
JDA	—Japan Defense Agency
JRC	—Joint Research Centers (European Community)
JSEP	—Joint Services Electronics Program
JSPD	—Joint Strategic Planning Document
KDD	—Kokusai Denshin Denwa (Japan)
LABCOM	—Laboratory Command
LAMPF	—Los Alamos Meson Physics Facility
LAN	—local area network
LHX	—Light Helicopter Experimental
MADOM	—Magneto-acoustic Detection of Mines
MIL-STD	—Military Standard
MITI	—Ministry of International Trade and Industry (Japan)
MMIC	—Monolithic Microwave Integrated Circuit
MoD	—Ministry of Defense (U.K.)
NASA	—National Aeronautics and Space Administration
NDI	—non-developmental items
NIF	—Naval Industrial Fund
NIST	—National Institute of Standards and Technology
NOSC	—Naval Ocean Systems Center
NRL	—Naval Research Laboratory
NSF	—National Science Foundation
NSIA	—National Security Industrial Association
NTT	—Nippon Telephone and Telegraph (Japan)
NWC	—Naval Weapons Center
O&S	—Operations and Support
ODDR&E	—Office of the Director of Defense Research and Engineering

OECD	—Organization for Economic Cooperation and Development
OMB	—Office of Management and Budget
OPM	—Office of Personnel Management
OSD	—Office of the Secretary of Defense
OSTP	--Office of Science and Technology Policy
OTA	—Office of Technology Assessment
PC	—personal computer
PE	—Program Element
PEO	—Program Executive Officer
PI	—Principal Investigator
PMC	—polymer matrix composite
PPBS	—Program Planning and Budgeting System
R&AT	—Research and Advanced Technology
R&D	—research and development
R&LM	—Research and Laboratory Management
RD&E	—Research, Development, and Evaluation
RDT&E	—Research, Development, Testing, and Evaluation
S&T	—science and technology
SDI	—Strategic Defense Initiative
SDIO	—Strategic Defense Initiative Organization
SES	—Senior Executive Service
STAR	—Strategic Technologies for the Army
STARS	—Software Technology for Adaptable Reliable Systems
TCP	—Technology Coordinating Panel
TOA	—Total Obligational Authority
TRDI	—Technical Research and Development Institute (Japan)
TSG	—The Surgeon General
UAV	—Unmanned Airborne Vehicle
URC	—University Research Centre (U.K.)
URI	—University Research Initiatives
USD(A)	—Under Secretary of Defense for Acquisition
USD(R&E)	—Under Secretary of Defense for Research and Engineering

Chapter 1

Introduction

Chapter 1

Introduction

Not long ago, the United States was the undisputed technological leader of the world. U.S. military equipment was meaningfully and undeniably more sophisticated than that of the Soviet Union, and our allies sought American technology for their own defense efforts. American companies developed and sold high-technology products to a world that could not produce them competitively. Defense-related developments led American technology and often "spun-off" into the civilian sector, creating products and whole industries. This reinforced a U.S. defense posture based on using technological superiority to offset whatever advantages the Soviet Union and other potential adversaries might have.

As we approach the 21st century, much has changed. The model of U.S. technology leading the world, with defense technology leading the United States, still retains some validity. But it is a diminishingly accurate image of reality. Soviet defense technology increasingly approaches our own, and sophisticated weapons appear in the hands of third world nations not long after their introduction into Western and Soviet arsenals. At the same time, the U.S. military has been plagued with complex systems that do not work as expected, work only after expensive fixes, or simply do not work. Most are high-priced and take a long time to develop. Increasingly, leading edge technology comes from an internationalized, civilian-oriented economy, which puts a premium on exploiting technology as well as developing it.

As a result, the Nation faces a complex set of interrelated problems that bear on its ability to continue to develop and manufacture in sufficient quantity the technologically advanced materiel on which we base our national security posture. There are specific concerns about: 1) the continued ability of the Department of Defense (DoD) and its contractors to develop the technologies it needs; 2) the ability of DoD and the defense industries to turn these technologies into useful, affordable products in a timely fashion; and 3) the ability of DoD to exploit the technology that is being developed worldwide in the private civil sector.

Concern over the availability of the latest technology for defense applications, and the ability of U.S. industry to engineer and produce equipment based on that technology rapidly and affordably, led the Senate Armed Services Committee to request that OTA undertake an assessment of the defense technology base. This is the second report of that assessment. The previous report, *The Defense Technology Base: Introduction and Overview*,[1] described what the defense technology base is and presented the major problems facing the Nation. This report looks in depth into some of the issues raised in the previous report. It identifies strengths and weaknesses of the U.S. defense technology base and analyzes options for enhancing the strengths and remedying the weaknesses.

The summary of this report (ch. 3) is divided into three sections. The first addresses the strategic management of DoD technology base programs. It examines the system by which the goals of the technology base programs are identified as well as the methods used to allocate resources in order to reach those goals. The emphasis there is on the role played by the Office of the Secretary of Defense (OSD) in guiding and coordinating the efforts of the Army, Navy, Air Force, and other DoD elements. It also addresses the management of the laboratories run by the three Services. These issues are explored in greater detail in chapters 4 through 7. The second section of the summary analyzes delays in getting technology into the field (see ch. 8 for supporting details). The final section is concerned with "dual use" technology, i.e., technology used in both the civilian and defense sectors (see ch. 9). Volume 2 of this report contains detailed supporting material on selected topics for those wishing to explore them in greater detail.

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[1] U.S. Congress, Office of Technology Assessment, *The Defense Technology Base: Introduction and Overview—A Special Report*, OTA-ISC-374 (Washington, DC: U.S. Government Printing Office, March 1988).

The remainder of this chapter provides a brief background on the topics of the report: management of defense technology base programs and facilities; technology transition; and dual-use technology. Those familiar with these subjects may wish to skip directly to chapter 2, which presents issues and options for Congress.

A large part of the technology that ultimately winds up in weapons and other defense systems is either developed or directly sponsored by DoD. This is particularly true of technology that is altogether new, makes a major difference in the performance of defense equipment, and is of little interest to commercial industry. How DoD runs its technology base programs is therefore of major importance. In recent years DoD has spent roughly $9 billion per year on its technology base programs: research (budget category 6.1), exploratory development (6.2), and advanced technology demonstration (6.3A). Roughly 40 percent of this is spent by the three Service departments (Army, Navy, and Air Force). Another 14 percent is controlled by the Defense Advanced Research Projects Agency (DARPA, formerly ARPA). Another 39 percent finances the Strategic Defense Initiative Organization (SDIO).[2] Although all of SDIO's funds are allocated in the 6.3A budget category, according to SDIO only about 15 to 20 percent is actually spent on technology base activities.

The three Services run their technology base programs and their R&D institutions differently.[3] Some of this is the result of recent planning, while much of it results from organizational "cultures" developed over many years. The Army's effort emphasizes decentralization. The Army runs some relatively small research laboratories which focus on selected topics, while larger research, development, and engineering centers are closely tied to "buying commands."[4] The Navy stresses in-house research and development both in the Naval Research Laboratory, a broad-based corporate lab that serves and underpins the Navy's entire technology effort, and in full-spectrum research and development (R&D) centers that nurture ideas from basic research through preproduction stages. These centers have traditional ties to the equipment needs of various functional parts of the operational Navy, but are not formally tied to specific buying commands. The Air Force, which contracts out more of its R&D effort than either of the other Services, centralizes its efforts within the Air Force Systems Command. Its technology base programs are seen as a link between buying commands (the divisions of Systems Command) and the defense industry. The basic theme is to buy technology and make sure it gets to industry. The Air Force has recently adopted the position that technology base programs should be a "corporate investment" funded at some fixed fraction of the budget. The Air Force puts a greater emphasis on R&D-related career paths than do the other Services.

With such diversity (including that added by DARPA, the other defense agencies and SDIO), if the program is to have overall planning and coordination—and not everyone agrees that it should—leadership almost has to come from the Office of the Secretary of Defense.

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[2] Other defense agencies account for approximately 7 percent of DoD technology base program funding. (See footnote 1, p. 19 of this report.)

[3] All three, however, orient their programs heavily toward current product areas. Nontraditional ideas do not fit well into the system.

[4] A buying command is one of a number of organizations within the Armed Services responsible for developing and buying military equipment and systems.

Actual R&D is performed primarily by industry, universities, and the laboratories run by the Services.[5] In most cases laboratory is a misnomer, although a convenient shorthand. These latter institutions, as a group, perform technology base work in addition to advanced and even full-scale development. They also provide other functions to DoD. Their efforts are generally divided among performing in-house work, contracting out work (and monitoring contractors' efforts), and providing technical advice to program managers and buying commands (a function often referred to as being "smart buyers"). It is very difficult to describe a typical DoD lab because they differ in size, in the mix of these functions, and in a number of other basic elements. However, what they all have in common is that they are owned and run by the government, staffed by government employees, and subject to a large number of laws and regulations. There has been a continuing and, in recent years, rising concern that they are inefficient, ineffective, self-serving and duplicative of industry work, and increasingly hampered in doing their jobs by the conditions of being part of the government.

DoD has some important unique characteristics, but it is not the only large organization that relies heavily on new technology nor the only establishment that runs R&D programs and facilities. Large corporations and the governments of other nations do the same. Their specific goals may not be the same: DoD buys defense equipment to meet a threat, corporations seek to develop and market products in a competitive market, and other nations seek to enhance their economic positions as well as their security. But all share the general goal of marshalling technology assets to achieve some purpose. To some extent, these other entities provide some of the background against which DoD must plan and execute its programs (certainly the evolution of the threat is another). But they also provide potential models of management techniques that might be useful to DoD in solving its management problems.

The technology base programs and laboratories produce technology, but that technology is of no use unless it makes its way into fielded systems that the military can use. There is great concern that it simply takes too long to get new technology into the field. Systems take upwards of 10 years to develop and produce, and when they finally become operational, they often embody technology that is viewed as obsolete, either because better technology exists in the labs or in industry, or because consumers can purchase better technology at their neighborhood stores. In the previous report, OTA found that delays are not a technology base problem: they occur after the technology is developed. However, delays are a major obstacle to keeping our technological lead in fielded equipment.

While a majority of the most visible technology in defense systems comes from DoD and companies that contract with it, a significant part comes from the "nondefense" sector. Mundane technology—like bolts—has often come from industries that sell to both military and civilian customers. And at the subcomponent level, much also comes from the civilian side. Increasingly, these "dual-use industries" are sources of advanced technology, sources from which DoD should be able to draw (and in some cases must draw, because the technology is ahead of what the defense world is building). Increasingly, leading-edge technology is developed in the civilian sector and then finds its way into defense applications. But government rules that make doing business with the government different from selling in the commercial sector create significant barriers to companies moving into government work. Some of these companies are heavily involved in defense work, while others now do little or no business in the defense sector. Moreover, dual-use industries are becoming increasingly internationalized, raising issues of the competitiveness of U.S. firms in the world market and dependence on foreign suppliers in defense procurement.

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[5] Work is also done by other government laboratories (e.g., the Department of Energy national labs and NASA labs) and various private profit-making and non-profit organizations.

DoD has become less able to drive the direction of technology. While some areas are pursued primarily for defense applications, others are molded by the consumer market. Large commercial markets generate enormous amounts of capital that fuel research and development. That R&D is primarily directed toward applications and products with large potential commercial payoffs. The relatively small amount of business represented by sales for defense applications is in many cases not significant enough to swing the direction of development. There are still many important areas of development that are primarily, or exclusively, defense-oriented. But the pattern of technology originating in the defense sector and "spinning off" into the commercial sector is being replaced by parallel development and, to use the Japanese term, "spin on" of commercial technology to military applications. Faced with this situation, DoD can buy cutting-edge technology developed in the civilian sector, or it can spend large amounts of money to keep a comparable leading edge resident in-house or with defense contractors.

As a consequence, DoD finds itself (or its contractors) having to buy from companies that do not need its business. Large aerospace companies have to play by DoD's rules: defense is their only business, or at least an overwhelming component of their business. But small, leading-edge technology companies can make much more money in the private sector without the trouble of playing by government rules. They can opt out of doing defense work.

This report examines dual-use industries through the mechanism of case studies, concentrating on three industries: advanced composites, fiber optics, and software. These present different perspectives. The advanced composites industry is heavily involved in defense business, but U.S. companies may see their commercial base erode as international competition heats up. Moreover, many of the major companies are international or integrated with foreign firms. U.S. fiber optics producers now sell very little for defense applications. But DoD has important uses for their products. Government buying practices form major barriers to these companies doing business in the defense market, and they are beginning to face stiff competition in the civilian market from foreign competitors. Finally, the software industry is one that straddles both worlds, and moves very rapidly. Software is at the heart of most new defense systems, particularly command, control, communications, and battle management systems.

All of these topics have been the subject of numerous studies, which have produced conflicting conclusions. This report pulls together much of that work, along with original research and analysis. Moreover, while DoD management and industrial/trade issues have been the subject of legislation and proposed legislation, the problems are not yet solved. The next chapter discusses the major issues before Congress.

Chapter 2

Options for Congress

Chapter 2

Options for Congress

The U.S. defense effort rests on a strong, broad, dynamic base of research and development. Government and private institutions, and civil and military establishments all contribute. But this defense technology base is also characterized by:

- a heavy burden of government rules, regulations, safeguards, and procedures that stifle the ability of the Department of Defense (DoD) to develop and exploit technology;
- the lack of an effective system for high-level planning and coordination; and
- the lack of a clear government policy and coherent strategy for dealing effectively with dynamic trends in the international high-technology economy.

To those who have followed defense industry, technology, and procurement, none of this will come as a surprise. These problems—and more—have been noted and studied for at least three decades. But despite repeated attempts to fix it, the system has remained resistant to major improvements. Indeed, the major problems have continued to worsen, although probably more slowly than if no measures had been taken.

The U.S. is not faced with a defense technology base that is in deep crisis. The Services and other defense activities fund a great diversity of research and development, run a large number of laboratories that do credible—and often outstanding—work, and successfully exploit that technology and technology developed elsewhere. But the process has a number of serious shortcomings that may be amenable to significant improvement. Moreover, important recent trends threaten to intensify these shortcomings and magnify their importance. U.S. leadership in high-technology industries that are vital to defense is eroding in the face of strong international competition. Budget restrictions predicted both by Congress and by the Administration will reduce funding for technology base activities at a time when the costs of research and development are increasing. And DoD's ability to compete successfully for key technical and managerial personnel is declining.

On top of all this, a heavy burden of rules and regulations impedes the development and exploitation of technology and the successful transition of developments into fielded systems. The accumulated actions of past Congresses are a major contributor to the difficulties. Laws passed for a variety of good reasons, taken together, bog the system down. Lack of clear policy on the part of both Congress and the executive branch impedes the solving of important problems.

Virtually all the easy solutions have been tried. It is unlikely that any fruitful but painless approaches remain. Congress and the executive branch will have to face some hard choices. These include altering institutional arrangements that—despite their deficiencies—have become comfortable, and sacrificing existing goals in order to achieve more efficient development and exploitation of technology.

Based on the analysis in this report, OTA has identified seven basic issues that profoundly affect the welfare of the defense technology base. These are not specific action items, but rather broad agenda items that warrant congressional attention. For each of these there are many different choices as to what individual policy directions to take, and within those, a myriad of measures (and choices among measures) for implementation. Implementation is clearly important, for without any sense of how to implement a policy, it remains simply an abstraction. There are options that can be implemented only through legislation, because today the law forbids them or provides no way to make them happen. And there are options that can be implemented without changing the law—through executive action or changes in DoD's internal regulations. Congress can have a hand in effecting these sorts of changes by making its wishes known or by using its considerable powers of persuasion.

Chapters 7, 8, and 9 discuss various specific policy options.

ISSUE 1: Reforming the Defense Acquisition System

The defense acquisition system is a major contributor to the long delays in getting new technology into the field and erects formidable barriers to exploiting technology developed in the civilian sector. While

Congress did not intend the system to be slow, cumbersome, and inefficient, laws passed to foster goals other than efficient procurement have made it so.

The system has weathered many attempts at reform because its problems are rooted in several basic causes. It is dictated in part by our basic system of government which demands checks and balances on the expenditures of large amounts of public funds, provides for a tug and pull between the interests of the executive branch and those of Congress, and permits both branches to reevaluate programs yearly in light of changing factors and interests. But much of the problem can be traced to laws that Congress has enacted to curb abuses and to foster goals other than efficient procurement of defense equipment. Laws and regulations have been added to ensure:

- civilian control over military procurement,
- Administration control over Service activities,
- congressional control,
- protection of congressional constituent interests,
- environmental protection,
- fairness,
- competition,
- accountability,
- honesty,
- controllable business practices,
- minority interests,
- small business interests,
- protection against conflicts of interest, and
- prevention of large profits at taxpayer expense.

These many ends often conflict with each other and with the objective of quick and efficient procurement, which leads to compromises that can satisfy few, if any, completely. Thus, the consequences of achieving these other objectives have included high costs, long procurement times, inefficient production, and restricted access to technology.

To promote these and other goals, the government has developed business practices and criteria that differ markedly from those of the civilian market. Buyer and seller have an adversary relationship; accountability is stressed over efficiency and price; and the government insists on visibility into how its contractors conduct their business. Government imposes restrictions on profits, trade secrets, and accounting procedures that are at variance with typical commercial practices. This discourages many innovative companies from seeking defense business.

History provides little hope that a few clever, relatively painless moves will be sufficient to make the system significantly more efficient while satisfying other goals. **If Congress is serious about making the system work better, it will have to face some hard choices.** One choice is to give efficient procurement greater emphasis over other goals. This would most likely mean that the system would become less fair, less competitive, less accountable, less responsive to minority and small business interests, etc. Another option would be for Congress to give up some of the power it has over major defense programs, or to curtail sharply some of the many centers of power within the executive branch. This would not necessarily make any particular program run better—two layers of management could be just as ineffective as 20—but it would remove major impediments. Instituting multi-year budgeting, which could also make programs run more quickly and smoothly, would likewise require both Congress and the executive branch to give up some power. Finally, Congress could loosen up the rules under which DoD conducts business, allowing business practices to move closer to those of the private sector. But inherent differences between government and private operations will always remain. For example, the government is accountable for the expenditure of public funds and is very sensitive to allegations of misuse. Where a business would be willing to absorb some pilfering if it were exceeded by the cost of prevention, the government is usually willing to spend whatever is necessary to prevent fraud.

Few such moves would come for free. For example, relaxing accountability rules could make it easier for companies to cheat the government. It may well be that, weighing all these factors together, Congress will decide that the current balance among all these interests is proper, and that inefficient defense procurement is an acceptable cost. While concerns for efficient procurement will push in the direction of loosening up the system, a need to respond to a recent history of procurement scandals, failed programs, and high-cost low-quality equipment will likely push in the opposite direction.

ISSUE 2: Independent Research and Development (IR&D) Recovery

Current law permits companies having contracts with DoD to bill to the government, as a cost of doing business, part of the cost of their internally generated R&D program. Industry generally believes that current rates of recovery are inadequate. Some think recovery rates are too high. DoD cannot seem to present a coherent position. IR&D recovery is not treated in this assessment, but it is very likely to be on the congressional agenda. Interested readers are referred to OTA's previous report *The Defense Technology Base: Introduction and Overview.*[1]

ISSUE 3: Reforming the DoD Laboratory System

As a whole, the DoD laboratory system performs its function of supporting defense procurement. As a group, laboratory managers are capable and experienced and provide much of the corporate memory for technology base activities. But the system is vast, complicated, and uneven in performance. The structure of the system as a whole—the number, types, sizes, orientations, and institutional connections of the labs—may be restricting their utility and effectiveness. Moreover, the management system under which these government owned and operated facilities are run is rendering it increasingly difficult for them to function effectively. A long list of rules impedes their daily operations and makes them increasingly unable to compete for highly qualified scientists and engineers. In general, Congress can choose to:

- reform the system itself,
- order DoD to reform it according to congressional guidelines, or
- leave the job to DoD.

Whatever course Congress chooses, it is unlikely that the correct approach will be either simple or obvious.

There are three basic approaches to reforming lab management. The least disruptive would be to alter, within the current civil service system, the rules under which they operate. This could include:

- extending the principal features of the NOSC/China Lake personnel experiment to other labs,
- permitting the labs expedited procurement procedures for scientific equipment and services, and
- providing multi-year funding.

Alternatively, Congress could decide that R&D is inherently different from other government activities, and that the labs should be allowed to operate differently from the rest of DoD. This might include permitting salaries for scientists and engineers to rise above current civil service ceilings and allowing the labs to build and modernize facilities by going outside the military construction process. The most radical approach would be to convert some or all of these facilities to government-owned, contractor-operated (GOCO) facilities, like the Energy Department National Laboratories. Conversion to GOCO could solve some of these problems, but would be no panacea.

Congress should also seriously consider altering the overall structure of the laboratory system. This could include closing some labs, consolidating others, shifting the internal make-up and missions of some, and creating new ones. Corporate research labs, like the Naval Research Laboratory, might be established for all the Services; or the in-house capabilities of many labs could be greatly improved. In the process, the system should get simpler, not more complicated. Greater integration of DoD labs with other government labs—reform of the overall government lab system—might also be considered. This could include forming research centers to spearhead major thrusts into areas of particular significance for both defense and commercial needs. These would be drastic steps requiring careful, detailed study and assessment of the individual labs before implementation. If done correctly, they could lead to greatly improved benefits from DoD R&D expenditures. If done carelessly, they could be counterproductive. At the heart of the process would be devising a system for evaluating the performance of the laboratories and their component parts. This ought to include the quality of work as well as its relevance to both identified Service needs and potential future advances.

Restructuring the lab system may be a necessary response to budget pressures that reduce funds available to run them. Significant reductions could be accommodated by reducing all efforts proportionately, but this would reduce good work as well as bad. Other approaches are closing the least productive and useful labs or effecting a more extreme restructuring of the entire system to maximize performance and utility at a lower overall level of effort.

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[1] Released March 1988, report No. OTA-ISC-374. Available from the U.S. Government Printing Office, Washington, DC.

ISSUE 4: Reforming Strategic Planning of Research and Development Programs

Unlike many governments and large corporations, the Department of Defense does not have a central headquarters-level system for planning and coordinating its technology base programs. Planning is carried out by the Services, the defense agencies, and the Strategic Defense Initiative Organization (SDIO); coordination among similar projects is done at the laboratory level. This lack of central focus is repeated both higher up the chain—at the overall national level—and within the individual Services.[2] This is not necessarily bad. If centralization stifles unplanned innovation and healthy competition, fails to support Service needs, or results in decisionmaking by the uninformed, then it is counterproductive. However, lack of overall planning can lead to wasteful duplication of efforts, lack of critical mass to solve common problems, fractionated efforts, and inattention to areas that are on no component organization's agenda. It also risks failing to identify areas of common or overarching significance. If there is to be strategic planning and central coordination, it will have to be done by the Office of the Secretary of Defense (OSD). Congress should decide whether—as many DoD studies have advocated—OSD ought to be given greater power (or encouraged to exercise the power the law already gives it) to plan, coordinate, and oversee technology base programs; or whether Service dominance should be supported and reinforced. More forcefully, Congress could order OSD to develop a strategic planning process to lead to a coordinated, department-wide technology base investment strategy.

As currently organized, OSD oversees Service technology base programs at one organizational level, DARPA at a second, and SDIO only at the highest level. This inhibits real coordination. Moreover, it leads to the lack of a high-level advocate within OSD exclusively for technology base programs, lowering the status of technology base programs within both DoD and Congress.

Strategic planning and program coordination are different from central management. The former refers to a strategic OSD planning function providing the ability to orchestrate the entire program. OSD could perform this planning role from a broad perspective over all the technology base activities that the individual Services do not have, but it would lack the detailed information and insight into the workings of specific programs necessary to manage them effectively. Planning and coordinating programs and then letting the extensive Service R&D organizations manage them is different from aggregating similar programs and managing them from OSD.

Congress could also define more clearly what its own role is. It seems unlikely that Congress can provide direction to the thousands of individual projects. Congress could actively involve itself in the strategic planning process or confine its activities to demanding that OSD produce and defend a strategic R&D plan.

ISSUE 5: Reforming Government Personnel Practices

Recruiting and retaining qualified scientists and engineers is a major problem for DoD laboratories. In the current sellers' market, government salaries and benefits for technically trained personnel are not generally competitive with either industry or universities. Many DoD labs have given up trying to recruit the best and the brightest. Loosening up the rigid civil service salary structure is a principal component of ideas to reform lab management, and being able to pay competitively—above civil service ceilings—is a major incentive for converting labs to GOCO status. Federal pay raises, if they are enacted and applied in any significant way to scientists and engineers, could substantially help the situation; alternatively, Congress could consider a separate pay scale for scientists and engineers more in line with industry and academia. This may not be a permanent problem, since the market for scientists and engineers tends to be cyclic. But until such time as it turns around, defense technology base efforts are being hurt by a system that cannot adjust to the market. It is also possible that this time the market will not turn around, that the current expansion in high-technology industry—coupled with demographic trends—will keep the supply short for a long time to come. Congress may also want to consider efforts to increase the number of students in technical disciplines. Defense efforts are particularly hard hit by shortages because they mostly require U.S. citizens and can take little advantage of the large number of foreign graduate students in U.S. universities.[3]

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[2] The Services seem to exercise more influence over their components than OSD does over the Services.

Some observers see similar problems in attracting good managers of acquisition and technology base programs. People with the requisite skills and knowledge can command greater salaries in industry, and are reluctant to work for DoD. "Revolving door" rules are also a disincentive to government service. Congress may wish to consider reviewing salary levels. It may also be worthwhile for Congress to gain deeper insights into the inhibitory effects of other employment restrictions and reconsider them in this light.

ISSUE 6: Fostering Greater Coordination Between Defense and Civil Research and Development

National defense benefits from a vibrant civilian technology base. Civilian research provides another large source of technology that finds its way into defense systems, and effective civilian R&D underpins a strong economy that provides greater revenues for defense efforts. The ability of the military to achieve and maintain leading-edge technology will, in many cases, depend on the health of corresponding civilian industries. In a very general sense, economic security is a major component of national security; the ability of the United States to compete economically is intertwined with its ability to compete militarily.

The U.S. defense and civil sectors are not isolated from each other, but they are far from closely coupled. Two relatively separate sectors have evolved—one military and the other commercial. The diffusion of civilian technology into defense systems is hampered, as is the availability for commercial purposes of technology developed in the military sector. Some of this is unavoidable: security often demands that some technology be kept under wraps. But much is the result of government business rules that erect barriers to commercial companies selling to DoD and of a weak, high-level technology policy apparatus.

Other industrialized nations—particularly in Western Europe and Japan—construct their technology efforts with a greater emphasis on economic development over military development than does the United States. They are increasingly demanding that military technology support commercial development whenever possible. In Japan, almost all technology is developed for commercial purposes, and some of it is then exploited for military uses. What is appropriate for these other nations is not necessarily good for the United States, since neither Japan nor any Western European nation aspires to be a superpower. However, these are the nations with which the United States is competing economically. We may be able to benefit from making both military and civilian R&D do double duty.

There are several things Congress could do to foster greater symbiosis of civil and military technology. Steps could be taken to expand the availability for commercial exploitation of the vast amount of R&D done in DoD laboratories and under contract to DoD. Tying the Defense laboratories more closely to those of other agencies—for example by fostering exchanges of personnel or forming major research centers for dual-use technology—could benefit both military and civilian developments. Both the development of technology and its transition into engineering could be helped by movement of technical personnel between government and industry.

The acquisition system could be reformed to make it easier for DoD to do business with innovative companies in the commercial high-technology industries. Government regulations on profits, data rights, and accounting procedures all discourage these companies from seeking defense business.

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[3] The question of potential shortfalls in the future supply of scientists and engineers is addressed in U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School*, OTA-SET-377 (Washington, DC: U.S. Government Printing Office, June 1988); and U.S. Congress, Office of Technology Assessment, *Higher Education for Scientists and Engineers—Background Paper*, OTA-BP-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989).

Congress may find it worthwhile to reconsider current mechanisms for setting technology policies at the highest levels of government. In particular, it may wish to provide for a high-level organization that would oversee and coordinate major government-sponsored R&D programs.

ISSUE 7: Dealing With International Trends in High-Technology Industry

The United States is failing to maintain a competitive commercial base for some technologies that are important for defense procurement. Long standing industrial and trade policies may have to be reformed if the United States is to maintain the industrial capacity necessary to support essential dual-use technologies.

Both Congress and DoD have been concerned about the movement of high-technology industries offshore. This has spawned several responses, including attempts to legislate that DoD buy almost exclusively from domestic suppliers. This approach would probably minimize foreign content in U.S. defense systems, but it attacks the symptom rather than the cause. It would have little effect on the ability of U.S. companies to compete effectively in the international marketplace—a key to having healthy, leading-edge companies here for DoD to buy from.

Having dual-use companies in the United States and available to DoD requires that they be sufficiently competitive on the world market to stay in business. Defense business alone is not usually big enough to keep them afloat. And creating captive companies that exist only on assured DoD business will almost certainly guarantee that technology falls behind the state of the art. Furthermore, cutting ourselves off from foreign technology will mean depriving our defense efforts of important technology that is not available here but possibly is available to the Soviets on the open market.

The United States will have to deal with two fundamental phenomena. First, high technology is a worldwide enterprise. The United States no longer has a monopoly on it. We can change our position relative to the rest of the world, but it is extremely unlikely that we will regain the dominant position the United States once enjoyed. Second, individual companies and entire industries are becoming internationalized. It is becoming increasingly difficult (if not impossible) to define what an American company is. Plants in the United States are owned by foreign nationals or foreign-based corporations. And U.S. companies open plants in other nations. Moreover, international partnerships lead to foreign interests in U.S. ventures and partial U.S. ownership of foreign factories. Protecting U.S. interests and ensuring U.S. sources of supply are therefore not simple matters. This is complicated by the measures that other nations take to protect their companies and their home markets.

The United States has yet to begin to formulate a policy to deal with this situation, both with regard to defense procurement and as it relates to the future of the U.S. economy as a whole. Congress will be faced with decisions on how dependent on foreign sources DoD can be, which high-technology industries must be kept viable in the United States, how to maintain those industries, and how to protect U.S. defense needs as companies become internationalized. Congress will have to formulate policy with regard to foreign ownership of U.S. plants and foreign siting of U.S.-owned facilities—or encourage the Administration to do so.

The solution is almost certain to be found among the choices that lie between the two extremes of buying defense components only from U.S.-based and owned suppliers, and buying solely on the basis of getting the best deal. The former is likely to be incompatible with staying on the leading edge of technology, and the latter may well reduce the U.S. base of technology and manufacturing to a level that is insufficient in time of crisis if not in peacetime. These intermediate choices include buying from:

- U.S.-based foreign-owned companies,
- U.S.-owned companies regardless of location, and
- nearby sources (i.e., Canada or Mexico) regardless of ownership.

In formulating policy, the Nation will have to decide how important foreign ownership is and to what degree domestic siting of development and manufacture is necessary. That policy will have to take into account factors such as: international patterns of trade, manufacturing, and corporate ownership; the costs and opportunities of maintaining domestic capabilities; existing relations with other nations; and the effects of policy choices on foreign relations. It is one thing to be interdependent with an allied nation, and quite another, as the oil shocks of the 1970s demonstrated, to be dependent on just any nation. Every nation ultimately presents a different case, but the spectrum ranges from Canada—which is adjacent, a NATO ally, and defined as part of the North American industrial base—through our European NATO partners, Japan, other European trading partners, and ultimately to nations with which our ties are very uncertain.

The intricacies of formulating policy are illustrated by the problems of trade in defense equipment with our NATO allies. The United States is pursuing multinational cooperation and integration of defense-related development programs through vehicles such as the Nunn Amendment, both for political-military reasons and to promote sales for U.S. defense firms. But these actions will also lead to greater competition from European defense companies in the United States and abroad. Access to European technology will be offset by the diffusion of U.S. technology.

Policy decisions regarding foreign dependence for defense needs fall into the jurisdictions of DoD and the Armed Services Committees. But the broader issue of how the United States should deal with the international economic situation in order to achieve these and other goals will involve a much more diverse cast of players. Congress will have to decide both how it will approach the problem in a manageable way, and what restructuring might be necessary within the executive branch.

Chapter 3

Summary

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Chapter 3

Summary

MANAGEMENT OF PROGRAMS AND FACILITIES

The system used by the Department of Defense (DoD) to run its technology base programs is dominated by two major characteristics that are practically unique among large technology-based organizations. First, the system is inherently decentralized, with planning and management dominated by a bottom-up approach. Second, it relies heavily (although not exclusively) on a large, diverse group of government owned and operated laboratories devoted to defense research.

Planning of technology base programs is done primarily by the Army, Navy, Air Force, DARPA (Defense Advanced Research Projects Agency) and the other defense agencies, and SDIO (the Strategic Defense Initiative Organization).[1] The Office of the Secretary of Defense (OSD) primarily serves as a monitor and data collector, deferring to these component organizations on matters of program direction. OSD collects budget requests and passes them to Congress; after the funding is approved, the component organizations run their own programs. Within OSD there is a hierarchy of oversight that inhibits rational integration of programs: the Services report at one level, DARPA reports one level up, and SDIO reports only to the Secretary of Defense. While not unique in running its programs this way, DoD follows a minority path. Most organizations exert much more top-down coordination and control over planning and management of technology programs.

The labs owned and run by DoD have two general shortcomings. First, most are not strictly laboratories and lack the multidisciplinary pool of talent necessary to be effective in developing a broad range of modern technology. Although they interact, they are generally independent of each other. Developing technology is not the only (or even the primary) mission of most of these labs, but access to that capability underlies the ability to perform other missions. Second, the government-owned, government-operated (GOGO) management arrangement has created many problems that impair the ability of the labs to function effectively. Other organizations structure their lab systems and lab management differently.

Worldwide, there are three major trends in the planning, management, and performance of technology development: top-down planning; centralized management; and collaboration. Moreover, among the governments of other industrialized nations there is a movement away from concentration on defense research and toward emphasizing civilian research that can be exploited for both economic and defense gains, as well as a movement away from government ownership of laboratories.

Department of Defense Technology Base Programs

The Department of Defense does not have a centralized system for strategic planning of technology base programs. It has a federated system in which the central authority—the Office of the Under Secretary of Defense for Acquisition—plays an advisory and coordination role, but either lacks or fails to exercise the power to make major decisions. Those decisions are made by the component organizations—the Services, DARPA, and SDIO. The planning process is both top-down and bottom-up, but it is clearly dominated by the bottom-up approach: most real decisions are made within the component organizations. OSD provides general guidance and reviews Service programs, but does not exercise any strong role in molding them. Attempts by OSD to mold programs (usually to keep to budget ceilings) are often viewed by the Services as uninformed, capricious, and arbitrary. This arrangement generally results in OSD not being able to guide or coordinate the technology base programs. However, OSD has in the past provided leadership for some special cross-Service programs, such as VHSIC, MMIC, SEI, and STARS.[2]

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[1] In fiscal year 1989 the three Services together will spend 40.2% of the technology base funding (6.1 plus 6.2 plus 6.3A). SDIO will spend 39.3%; DARPA will get 13.8%; and the remaining 6.7% will be spent by the other defense agencies—the Defense Nuclear Agency, the Defense Communication Agency, the Defense Mapping Agency, the Defense Intelligence Agency, the Defense Logistics Agency, and the National Security Agency. Among the agencies, DARPA occupies a special place because of its role as a source of R&D to complement Service programs. Efforts of the other agencies tend to be more specialized.

This system is not necessarily bad, but it seems to be ineffective in producing a coherent technology base program. Those who believe OSD ought to provide strong leadership find the current system disappointing. To those who believe that OSD ought not to be controlling technology planning, it is the proper approach, even if OSD occasionally weighs in too heavily and disrupts programs. They believe that the users of technology—the Services—ought to plan and control its development, that giving too much power to OSD risks losing Service support for technology base programs, and that the Services are better able than OSD staff to preserve technology base funding.

Central planning and central management are two separate but related issues. Without top-down planning a program lacks, as DoD's currently does, a broad consistency of purpose and coordination to ensure that important areas are not left unaddressed, and that healthy competition among competing developments does not become wasteful duplication. Central management can help ensure that the results of central planning are carried out, but it can also result in control of programs by those least able to understand them.

Organizationally, the problems arise from two sources. First, OSD lacks either the ability or the will to exercise power over the Services. And second, there is no one individual or office that serves as a focal point and coordination center for the technology base programs of all the component organizations. This results in diffusing the power to plan and coordinate, and precludes establishing a high-level advocate for technology base programs who is free of competing interests. The Goldwater-Nichols reorganization changed the players and their titles, but did not correct these basic problems.

Within OSD, all technology base programs *with the exception of SDI* are the responsibility of the Undersecretary of Defense for Acquisition. This is shown schematically in figure 1. But the technology base is only one small part of what he is responsible for—he also oversees the rest of research, development, test, and evaluation (RDT&E) as well as all of procurement. DARPA reports directly to the Director of Defense Research and Engineering (DDR&E) for oversight, but oversight for the Army, Navy, and Air Force programs rests one level farther down the chain with the Deputy DDR&E for Research and Advanced Technology. The DDDR&E(R&AT) is the highest ranking official with responsibility only for technology base programs, but he only has responsibility for less than half the technology base. Thus, the Service programs are coordinated at the DDDR&E(R&AT) level, but they are coordinated with DARPA's program one level higher up the chain, and balanced with SDI only at the highest level. This produces a hierarchy of influence among these component organizations and a mismatch that makes it difficult to balance their demands.[3] Moreover, no one with the power to oversee the entire technology base program can be an advocate for it unencumbered by other, possibly conflicting, responsibilities.

Overall goals for technology base programs are supposed to be specified in the annual Defense Guidance document. But in reality, the Defense Guidance devotes little space to the technology base, providing only very general guidance that can be used to justify just about anything the Services, DARPA, and SDIO want to do. The result is that these component organizations plan more or less independently, based on internally generated criteria, and link their plans to the general language of the Defense Guidance. The OSD review of Service plans is predominantly a data-gathering exercise with little real power exerted from OSD. And real coordination is hampered because DARPA and SDIO programs (which together account for over half of the funding) are considered only at higher levels. Thus the Services and agencies dominate the planning process.[4]

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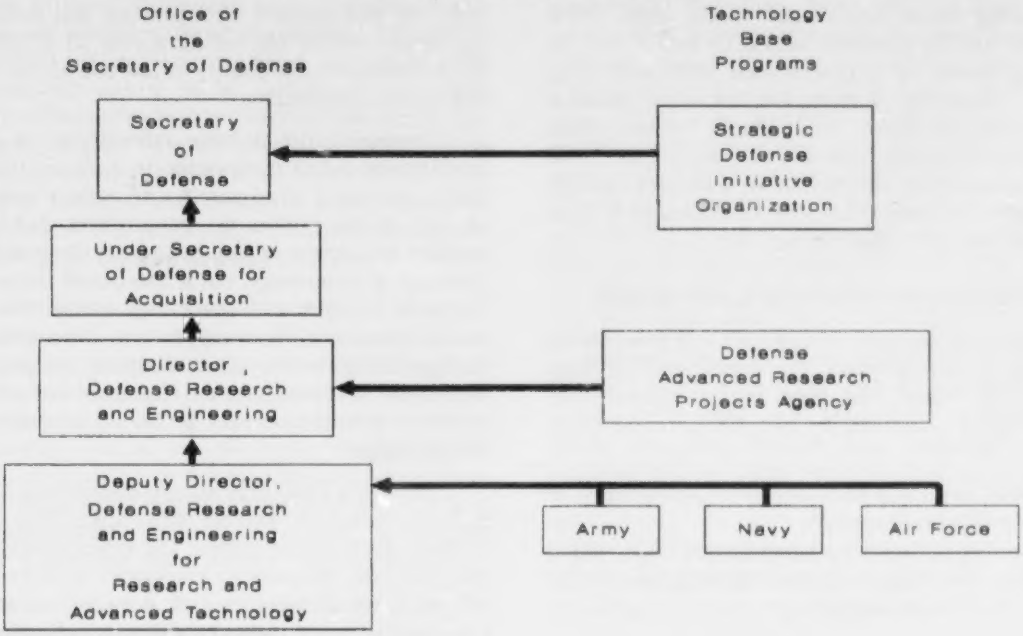
[2] Very High Speed Integrated Circuits; Monolithic Microwave Integrated Circuits; Software Engineering Institute; Software Technology for Adaptable, Reliable Systems.

[3] Manufacturing technology programs, vital to ensuring producibility of items, are accorded a generally lower level of oversight and advocacy than product technology programs.

[4] Top level planning is typically not done within the Services either; ideas come up from lower levels. However, in recent years the Services have been conducting high level studies of their future technology needs: Air Force Forecast II; Navy 21; and Strategic Technology for the Army. The Air Force had been planning some of its technology base program around the results of Forecast II.

Figure 1—A Hierarchy of Oversight


Office of the Secretary of Defense
Technology Base Programs
Secretary of Defense
Strategic Defense Initiative Organization
Under Secretary of Defense for Acquisition
Director, Defense Research and Engineering
Defense Advanced Research Projects Agency
Deputy Director, Defense Research and Engineering for Research and Advanced Technology
Army
Navy
Air Force

SOURCE: Office of Technology Assessment, 1989.

It is not the case that the Services do not talk to each other or to DARPA or SDIO. There is considerable coordination among projects having similar technical foci, but this occurs at the project level and not at the overall program level. There is much technical interchange but little programmatic coordination. OSD could exert strong influence at this level through its technology reviews, but it only conducts a few such reviews each year.

Because no single individual or office has responsibility for all technology base activities and only for the technology base, it is difficult to have a strong and consistent advocate for technology base both within the DoD bureaucracy and in relations with Congress and the Office of Management and Budget (OMB). (This problem is mirrored within the Services with similar results.) Nevertheless, OSD personnel spend a large part of their time defending technology base programs or answering congressional mail, leaving little time available to evaluate technology base programs. It is not surprising, therefore, that OSD and the Services do not have a systematic DoD-wide approach to evaluating technology base activities. Evaluating last year's programs is a key to planning next year's. If OSD personnel do not have the time to evaluate last year's programs, they lack a solid basis on which to judge Service plans for next year.

The structure of the bureaucracy is not the only contributor. The relationships among institutions within DoD also play a major role. The Services and DARPA have traditionally had the upper hand with OSD. SDIO was designed to be able to proceed without interference from OSD or the Services. Typically, this sort of "pecking order" will persist in the absence of positive actions to change it.

Personnel is another factor. Although OTA has encountered OSD staff who are competent, dedicated, and overworked, there is a consensus among experts that, like the labs, OSD suffers from restrictions that limit its ability to get and keep the best people. While experts are divided as to how to solve the problem, most agree that paying more and decreasing career restrictions would help. Some believe that the problems would be best solved by vesting power in a professional staff with long tenure, removing it from the hands of political appointees and other "short timers." Others think that only a constant infusion of "new blood" will help: rearranging the system so that very capable managers could take such jobs for a fixed term (e.g., 4 years) and then return to industry.

Department of Defense Laboratories

Reports on the shortcomings of DoD laboratories go back at least 30 years. The mind-numbing array of specific issues that these earlier reports have raised can be captured by two fundamental questions:

- Does the DoD have the type and quality of laboratories it needs?
- Are the management arrangements under which these laboratories are run inhibiting their ability to perform as needed?

Type and Quality of Laboratories

To be precise, DoD has no laboratories. The Army, Navy, and Air Force departments own and operate a large number of research, development, and engineering (RD&E) centers, none of which are laboratories in the pure sense, i.e., institutions solely for conducting research. These centers perform a variety of functions ranging from research through full-scale development to occasional limited-scale manufacture of military equipment items. The mix of activities varies from center to center, with some—such as the Naval Research Laboratory and the Army's Harry Diamond Laboratory—being more heavily oriented toward research than others. As a shorthand, the term "defense laboratories" is used to refer to these government owned and operated RD&E centers.[5]

The structures of the defense laboratories—how big they are, what kind of work they do, etc.—have evolved historically, based in part on the different procurement systems of the three Services and the roles each has seen for its laboratories. These structures are quite different among the labs. However, the management arrangements and modes of operation--which are similar across all of them—are a consequence primarily of law and also of DoD and Service regulations.

Comparing the defense laboratories to other government R&D institutions is difficult because DoD's role as a large purchasing agency makes it almost unique within the government. NASA is perhaps the closest analog because it too purchases products of technology, but it also builds things and conducts research and space exploration. The national laboratories that support the Department of Energy (DOE) build nuclear weapons and pursue a broad base of research for the furtherance of science. Industry, which also runs laboratories, ultimately builds things.

Comparing DoD labs among themselves is also difficult because no two are really alike. They differ in three distinct dimensions: the subject areas they focus on; the mix among categories of work (6.1, 6.2, etc.); and the weighting of their missions among a number of basic tasks. In addition to conducting research and development, these tasks include:

- buying R&D from contractors and monitoring the contracts;
- advising program offices on responding to proposals from industry to do development and production work (i.e., acting as "smart buyers" of technology);
- providing a base of technical expertise and know-how that can be drawn upon to solve problems as they arise or to follow new areas of technology;
- training young officers in science and engineering;
- solving technology-based problems (or equipment-based problems) encountered by field commands; and
- designing and producing very small numbers of special purpose items needed by field commands.

They also differ in size, source of funding, and the orientations and "cultures" of the organizations they primarily work for.

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[5] DoD is also supported by contractor owned and operated laboratories such as the John Hopkins University Applied Physics Lab and the MIT Lincoln Lab, and by national laboratories operated by contractors for DOE. For more information on the institutions that support the defense technology base see: *The Defense Technology Base: Introduction and Overview*, OTA-ISC-374 (Washington, DC: U.S. Government Printing Office, March 1988).

All of these differences make objective evaluations and comparative ratings of these institutions very difficult to perform. Most evaluations and comparisons appear to be subjective ones, even when performed by highly qualified individuals. For example, Service labs are frequently criticized for not doing top-flight science, especially when compared to national laboratories or major university laboratories; but performing scientific research is not the major mission of these facilities.

Nevertheless, there is a common thread among all the tasks the labs perform: they all require the laboratory to be a center of technical expertise. Most don't *require* the staff to be conducting research and contributing to the advancement of science or technology, but all *benefit* from a staff that has hands-on expertise: a staff member who is contributing to the leading edge is closer to it than one who is simply reading about it, and is more likely to get a seat at the table when the real experts meet.

There are three basic approaches to providing the research core of an R&D facility. The first is to build a large, diverse, multiprogram laboratory with a staff that does research in a broad range of disciplines. The DOE national laboratories fit this description, as do the corporate research centers of several very large corporations such as IBM, AT&T, and General Motors. These labs push forward the frontiers, provide a large pool of talent that can be directed and redirected to solve problems or follow new areas of technology, and provide a base of knowledge from which other labs can draw for more narrow applications. Staffs typically number well over 1,000 and are heavily weighted toward advanced degrees. The Naval Research Lab is the only DoD lab that fits this mold.

A second approach is to build labs with staffs of a few hundred that concentrate their efforts in one or a few areas. Several Army laboratories—Night Vision, Harry Diamond, Electronic Technology & Devices, etc.—are structured this way. These facilities can have programs that are at least as good as those of the multiprogram laboratories in a few selected areas. However, this focus is bought at the cost of loss of breadth and flexibility to respond to a broad range of problems. Moreover, as modern technology becomes more complex, even a single area of concentration can rest on a broad base of underlying disciplines. Size can constrain these laboratories from effectively pursuing their few areas of concentration and from shifting their focus. This problem of lack of critical mass is even more pronounced in the third type, the model followed by most Defense labs: a medium to large RD&E center with small cells of expertise embedded in it. These labs do not have in-house research as a focus, but as a supporting function. Hence the cells of expertise, however skillful and productive, tend to be narrow and thin: in some cases the departure of one or two key individuals could destroy that expertise.

In detail, the Army, Navy, and Air Force run their RD&E centers differently. But in general they all function the same way: technology generated in-house, in other Service labs, externally under contract, and any other place the staff has access to, is assimilated with the aim of transitioning it into the procurement system. The accumulated base of knowledge is used to advise the procurement officers regarding the technical qualities of various proposals to develop and build systems.

The central question is whether this system has been, and is really capable of, delivering the goods. Does the technology transit into and out of RD&E centers, and are the staffs up to the job? This is a very complex question requiring an intensive investigation, but it is absolutely key.

If the answer is "yes," Congress ought to stop worrying about the labs and let them get on with their work. Steps might be taken to make their jobs easier by easing management burdens. However, even if the labs are judged to be doing a good job, budget constraints may make it necessary to consider restructuring.

If the answer is "no," there are a number of steps that might be taken to fix things. These range from taking steps to ease management problems (which will be discussed below) to drastic reorganization of the entire system. Some involve centralizing, consolidating, closing, and moving institutions. **However, such steps have far-reaching consequences and can be nearly irreversible. They ought to be taken only after much deliberation.** One approach would have each RD&E center include or be closely associated with a large multipurpose laboratory, the small cells of expertise being replaced by a large, diverse pool of technical talent. Clearly, doing so for each RD&E center would be prohibitively expensive. An alternative approach would be to provide each Service, or DoD as a whole, with a central corporate lab and tie the RD&E centers closely to it. The Naval Research Lab might be a model. Smaller labs of more limited scope are a second choice, but because they are inherently less flexible than multiprogram labs, arrangements would have to be made either to shift their focus or close them down as the areas of technological interest shift. As an alternative to building up the research bases within the Services, greater use might be made of DOE national labs as technology bases for the Services. Consolidating facilities either within each Service or across Service lines under OSD could offset the cost of expanding the underlying labs. But this runs the risk of cutting the links of the RD&E centers to their parent buying commands and further restricting the transition of technology into the procurement system. Unless handled carefully, it could also sever the very important links of the labs to the field commands.

Management Structure of Laboratories

The problems that plague the Services' government-owned, government-operated laboratories (GOGOs) and the causes thereof have been extensively documented. They are inherent in the laws and regulations that govern the operations of these labs. While these laws and regulations have not changed greatly over decades, the trend within the last few years has been for their application to become more onerous, making the government labs less attractive places to work at a time when the market for technical talent has become much more competitive.

The difficulties fall into three related categories: problems in recruitment and retention; difficulties in conducting the day-to-day business transactions necessary to get the work done; and long delays in updating buildings and major equipment. The latter two are problems in their own right as well as contributors to personnel difficulties. Effective management is also impeded by funding that is often unpredictable and fluctuates from year to year.

Even premier laboratories, like the Naval Research Lab, are having difficulty attracting the best and the brightest. Many of the RD&E centers have all but given up trying: they now recruit from a small circle of mostly local schools and hope to "grow" their own in-house expertise. OTA's observations support the points made in earlier studies:

- most of the labs have difficulty hiring and retaining highly qualified personnel;
- the government is at a major disadvantage in competing with industry and academia; and
- the system makes it difficult to reward good performers, penalize the poor performers, or tie salary closely to performance.

The "NOSC/China Lake Experiment," in which the Navy loosened the salary structure for scientists and engineers at the Naval Ocean Systems Center and the Naval Weapons Center at China Lake, helped with recruiting and retention in the entry and midlevels. Similar novel approaches including salary structure and educational opportunities are under consideration by the Services. But since these do not raise the ceiling on salaries; they do little to solve the problem of attracting and retaining key senior people. Losing senior researchers is a double liability: exceptional senior people do exceptional work, and they also attract younger people, many of whom will accept otherwise less attractive work conditions in order to work with someone special.

Interesting work helps to attract and retain people. Good people stay if the work is challenging, if discretionary funding is available to allow them to "follow their noses," and if they have an opportunity to pursue a technical career without being sidetracked into management. But increasingly, technical people in Service labs can only get ahead if they become managers, and in those management jobs they spend an increasing amount of their time in administrative tasks and insulating their bench-level people from bureaucratic "paperwork" imposed from above.

At most DoD labs the Technical Director has little or no control over the most important support elements of his organization—the personnel office, the general counsel, the procurement office, etc., all of which report to parent commands. And construction of new facilities is handled out of military construction (MILCON) accounts for which the labs usually fight a difficult, and often losing, competition with a long list of other claimants. This results in obsolete facilities.

The Defense Science Board has recommended changing the laws and regulations that are causing the problems, loosening up the system to enable the Defense labs to compete more effectively. While this might be helpful, it would require a long list of changes in both legislation and government regulations. This involved agenda could be very difficult to complete. However, a congressional decision to treat the laboratories differently from other government offices might facilitate the changes.

An alternative would be to convert the labs to government-owned, contractor-operated (GOCO), or even to contractor owned and operated (COCO) facilities. This would seem an easy way out of the morass of government red tape. GOCOs do have greater management flexibility in personnel management, but the evidence for greater flexibility is ambiguous in areas other than personnel. GOCOs can pay higher salaries, can hire and fire more easily, and have much greater flexibility in rewarding good work and shifting personnel. They also display greater flexibility in shifting the focus of their work, and have some advantages—although not so dramatic—over GOGOs in their ability to purchase equipment and facilities.

DOE GOCOs appear to show a greater aggressiveness in seeking out and developing technology. And, at least in the design and manufacture of nuclear weapons, transition of technology into applications is more direct than it typically is in DoD. But this is not necessarily a consequence of their being GOCOs. Size, full-spectrum stance, and research-oriented culture are all contributors. So is the relationship that has evolved between DOE and its labs: the missions of the labs have been construed in a very broad way, facilitating changes in program directions as technology evolves.

While there are some real advantages to converting to contractor operation, there are some important offsetting factors. No government-funded institution can escape oversight merely by converting to contractor operation. Funds derive from congressional appropriations, and Congress holds senior officials of sponsoring agencies accountable for their use. Thus, the tendency is for the government to impose on its contractor laboratories many of the same rules and regulations it lives under. Consequently, with time GOCO labs tend to become more like government-operated laboratories. Government rules under which the sponsoring agencies operate tend to be passed down to the contractors, so the GOCOs are not free of the majority of government impediments. Government policy appears to be that even though government regulations do not apply to GOCOs, GOCO practices ought to be consistent with them. OTA found that the perception of "red tape" and the burden of bureaucratic paperwork reaching down almost to the bench level was no different at GOGOs, GOCOs, and COCOs.

Although there have been many studies of government labs since the 1962 Bell Report, none have questioned its finding that there are "certain functions which should under no circumstances be contracted out. The management and control of the Federal research and development effort must be firmly in the hands of full-time government officials clearly responsible to the President and Congress."[6] There are some functions that are inherently governmental: passing them off to contractors would raise major questions. For example, being a smart buyer and advising a program office on the technical merits of proposals is probably not a responsibility that ought ultimately to be entrusted to a contractor, although today contractors are part of that process.

One advantage of government labs—and a major function—is that they can respond immediately to problems that emerge in the field. Staff can be ordered to stop whatever they are doing and turn their attention to the problem at hand. This would be more difficult for contractors to do, unless the contract had been carefully crafted to allow for the contingency.[7] At several contractor operated facilities OTA was told that response times would have to be measured in months, if not years.

While all DoD labs could benefit from fewer restrictions, not all are equal candidates for conversion to GOCO status. Those that conduct in-house R&D would be better candidates than those that function primarily as "smart buyers." Similarly, those that cannot solve their management problems within the government system would be more likely candidates for conversion than those whose managers believe they can.

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[6] *Report to the President on Government Contracting for Research and Development*, reprinted in W.R. Nelson (ed.), *The Politics of Science* (New York, NY: Oxford University Press, 1968), p. 200.

[7] For example, level of effort support contracts.

Other Approaches

After examining a number of approaches used by other organizations to manage technology programs, some basic themes emerge that may be applicable to DoD management of its technology base programs and laboratories. First, in most governments and companies, R&D policy is approved at the upper levels of management and promulgated throughout the organization. Second, centralized control over research projects is the rule. It is supported by frequent reviews and combined with a readiness to cut losses when projects do not pan out and to buy technology outside the organization if that appears to be a more economic approach. Third, both public and private organizations are moving toward collaboration as a means of affording research of the magnitude dictated by modern technology. Finally, on a broader note, the Europeans appear to be moving toward the Japanese point of view that technology efforts ought to be focused on enhancing the economy: a strong high-tech economy will produce both more money available for defense and "spin-on" of technology for defense purposes.

For at least two decades the Europeans have been worried about their economic positions, particularly relative to the United States. But the emergence of Japan and other Asian nations as economic powers has greatly intensified their concerns. This has spurred efforts to integrate the European Community (EC), notably the movement to a "single Europe" in 1992. Moreover, as their fears of economic problems have increased, their anxiety over Soviet military power has receded. Hence the mood is to reduce the drain on the economy of defense oriented R&D, while increasing substantially research oriented toward civilian products. The Europeans are looking for ways to make defense R&D support civil production; defense labs are increasingly viewed as national assets that can be used to help make civilian industries productive. The trend appears to be to do research and exploratory development (the equivalent of 6.1 and 6.2) predominantly in civilian-oriented labs. Only in the advanced development stage would the work take on a more military-oriented cast. The prevailing philosophy appears to be that science and technology policy should be integrated whenever possible with economic and industrial policies. In this regard, the Europeans are moving away from the U.S. model and toward the Japanese model.

It is tempting to take the attitude that if our system has significant shortcomings we ought to adopt someone else's. But this approach is fraught with peril. While there are important lessons to be learned—and these general themes appear to be worth considering—it is not necessarily true that DoD can simply adopt some other system as its own. All organizations are different, and they do not all see themselves as solving the same problems. Management approaches tend to be rooted in corporate "culture" at least as much as they are the result of dispassionate analysis. It is somewhat dangerous to adopt the attitude that what works for some other organization ought to work for DoD. For example, the sheer scope and size of DoD's technology base activities dwarfs nearly every other organization examined, and might even rival the aggregate of them. Furthermore, it is not clear that other organizations are significantly more successful than DoD is in developing and nurturing technology and using it to good effect. The success story everyone immmediately turns to is Japan. But Americans are not, and do not behave like, Japanese. And the Japanese seek to use technology somewhat differently than does DoD.

Planning and Priorities

In contrast to DoD, in which a laissez-faire approach and "bottom-up" planning predominates, most Western European governments set national civil and military R&D objectives from the top. Working through central committees or advisory panels, cabinet-level officials set priorities and ensure that the goals are translated into specific programs in either government or private laboratories. The technical experts are usually left free to determine the composition of the specific programs, but they must be able to justify program relevance to higher authorities. In addition, the European Community is exerting an increasing top-down influence on the member nations' research programs. Exploiting allies' work and avoiding duplication of effort is a growing theme. The Japanese approach is perhaps less formal, emphasizing government/industry consensus building and the role of industry, but ultimately major decisions are made by a central body.

Industry generally follows a somewhat similar centralized approach. Major corporations typically have central procedures for establishing business objectives, including identifying the key technologies that are expected to contribute. Once these selections are made, the component companies are free to decide how to pursue them. But corporate oversight typically remains continuous and close.

There has been strong criticism that U.S. defense R&D focuses too much on the near term, both in government and in the private sector. European companies are even more likely than U.S. companies to spend their R&D money for near-term applications. This trend has become more pronounced recently in both Europe and the United States as technology base expenditures have declined as a proportion of defense spending. In contrast, however, budgets for long-term research—particularly civil research—are increasing for many European countries and for the EC. This is tied to a perceived linkage between R&D, economic competitiveness, and prosperity. Governments are seeking to improve their industries' competitive positions by making civil research the driver and blurring the distinction between civil and military R&D. The Europeans' short-term focus and declining funding in defense research appears to be offset by a longer term focus and more generous funding for civil research. In Japan, the government role is greatest in long-term developments for which the risks are high and the payoffs not evident.

Growing fear of Japanese and U.S. industrial competition has fostered European interest in large-scale, centrally directed technological initiatives. These have been largely multinational in nature, such as ESPRIT, EUREKA, RACE, and BRITE,[8] although there have been single nation programs such as the U.K. Alvey program. These are modeled, in part, after a succession of U.S. initiatives—beginning with the Manhattan project—that, while not always successful, propelled technology forward. Large collaborative efforts are also employed by the Japanese, but their efforts tend to have more industry funding and less government money.

A similar approach currently in favor in Europe and to an increasing extent within U.S. industry is to employ special research teams, or "centers of excellence," often in collaboration with universities or potential competitors. These groups concentrate on technologies where a large critical mass of personnel and other resources, or interdisciplinary research, is considered essential. U.S. examples are SEMATECH, the Electric Power Research Institute, Semiconductor Research Cooperative, and the Microelectronics and Computer Technology Corp.

Management and Control

European governments not only plan their R&D programs centrally, they also manage the execution of those programs centrally. Large companies also tend to keep tight central control. In both cases, the trend is also toward centralized control of laboratories in an attempt to establish the optimum balance between generic research and product-oriented (or mission-oriented) research.

DoD's laboratory system is basically mission-oriented, with most laboratories dedicated to specific warfare specialties. Mission focus provides a closer link between technology and military applications, but it also encourages duplication in facilities, resources, and projects. European labs and programs are increasingly organized along technology, not mission lines. In France, Germany, and the United Kingdom the defense research activites are planned, organized, and managed by central authorities independent of service requirements and development activities. Centrally managed civil research programs are generally oriented around generic technologies. Similarly, EC programs are directed toward enabling technologies, with applications left to industry.

DoD's extensive network of government owned and operated laboratories is unique among Western defense establishments. With the exception of the United Kingdom, European governments own few, if any defense labs, and the British are in the midst of drastically consolidating their laboratory system. However, there are many more European government-owned and government-sponsored laboratories doing civil research.

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[8] European Strategic Program for Research in Information Technology (ESPRIT); European Research Coordinating Agency (EUREKA); Research and Development in Advanced Communications for Europe (RACE); Basic Research into Industry Technology for Europe (BRITE).

Industry is generally moving in two directions. Most R&D is being moved out to the component companies. Some corporate research centers are being pruned back or even closed. As money gets tight, it is easy to view corporate research centers as expensive luxuries—"money sinks"—rather than as investments. But at the same time corporations are establishing corporate level centers of excellence in key technologies (or forming collaborative efforts in them). Technology is transferred to the product divisions, at least in part, by assigning personnel from the product divisions to temporary jobs in the central facilities and then moving them back to use and disseminate the technology they studied and helped develop. Industry is also moving in the direction of collaborative research, sharing the escalating costs of modern technology. This research is of necessity technology oriented, not mission oriented.

Collaboration, Coordination, and Technology Transfer

Collaboration in research is now a way of life. High costs and worldwide competitive pressures are forcing governments and industries to pool their resources. Collaborative projects play a central role in Japanese R&D. European governments and industries explored cooperative research in the 1970s and early 1980s, but in the mid 1980s growing concern that they were falling behind the United States and Japan led to a series of serious collaborative measures. Moreover, the European members of NATO, after more than 20 years of ad hoc collaboration on defense and other aerospace projects, are now working on establishing a coherent, systematic program of collaboration. Breaking down the long-standing barriers that have isolated European companies from each other and fragmented markets is an explicit objective of recent high-technology collaborative initiatives. In addition, European companies see that they each have to draw on a broader base of technology than was necessary in the past. Recognition that Germany's strong position in world trade is due, at least in part, to a collegial, collaborative relationship between industry, academia, and government also helped spur interest in collaboration.

U.S. companies are not only engaging in collaborative programs at home, they are also joining with European (and Japanese) companies in various ventures.

Applications: Transitioning Technology From Lab to Products

DoD has been criticized both for leaving technology in the lab too long, resulting in obsolete weapons, and for rushing it prematurely into production—which creates unreliable products. Neither allegation is without foundation. Technology transition is one of the most difficult problems of development. European governments and industries appear to be no better at technology transition than DoD is. Japan appears to have a unique success at transitioning technology rapidly and effectively from the lab into production. The Europeans appear to be studying and beginning to apply the Japanese experience. Teams of researchers, designers, engineers, manufacturing specialists, and even marketers are being brought together early in the life of a product in order to perform in parallel what usually gets done sequentially. The parallel development of process (manufacturing) technology and product technology is considered a particularly important factor.

Examples of the close relationship that is essential between research staff and those who develop specifications exist in all successful companies; but in large and diverse government organizations the liaison and communication that is required may be jeopardized by interdepartmental rivalries and parochialism which only strong management and direction can dispel. In DoD, requirements for new systems are set by the Service buying commands, and development is done by industry. These are obliged by law to stay at arms length; the government labs provide the primary link between them—and the labs are not always successful.

GETTING TECHNOLOGY INTO THE FIELD

Government officials and others have expressed concern and frustration over the age of technology in fielded U.S. systems, particularly those just beginning to roll off assembly lines. Comparisons usually take two forms. First, government and industry researchers have laboratory developments that are clearly superior to what is going into the field.

Second, dual-use technology in defense systems often lags significantly behind what is available in the consumer markets, and by the time a system has been in the field for 5 to 10 years it can seem outdated compared to what Ford or Radio Shack is selling.

Technology in production will always lag behind technology in the lab. Taking developments off the bench, engineering them into real systems, and getting those systems into production is a time-consuming process for military and civilian manufacturers, as well as for movie producers, think tanks, book publishers, and many other enterprises. Indeed, very little legislation moves instantaneously from brain storm to law. Major military systems are generally much more complicated than civilian products, and hence the product cycles are much longer.[9] In addition, the process of getting approval to begin a military project is generally considerably longer than the equivalent process in the consumer sector. Furthermore, military systems have long lives, and dealing with frequent updates is a logistical nightmare, so it is not surprising that changes occur much less frequently than the typical yearly changes in consumer products. It appears to make sense to change the current model Toyota because of a relatively small change in engine technology. (Indeed, it helps sales to tell consumers that this year's model is "all new" and "innovative," and technology is often changed just to enhance marketing.) But it makes absolutely no sense to rebuild the entire fleet of tanks every year to take similar changes into account. The problems of maintaining different equipment types in the field mean that decisions to update part of the total inventory, while often made, are not taken lightly. Finally, DoD is not in the business of developing and fielding technology for technology's sake; its job is to get better capabilities into the field in a reasonable time at a reasonable cost. Up to a point, it is not unreasonable to argue that new technology ought to buy its way onto a system.

Military-specific technology is usually the pacing technology for entire systems, determining the schedule for getting the system into the field and controlling the rate at which the dual-use technologies in the system get fielded. The entire acquisition system is geared to the pace set by these military technologies. It is often the case that after a system design is frozen, the commercial counterparts of technology embedded in it continue to move forward, sometimes dramatically, resulting in several generations of products before the military system is produced. This produces military systems that are not as advanced as some commercial products; but if responding to rapid changes in dual-use technology were to prevent freezing the design of a system long enough to get it into production, none of the technology would ever get produced.

Thus, while it can be misleading to compare fielded military technology to laboratory technology or selected consumer technology, it is important to ask whether new technology can get more quickly and more effectively into the field. (It is also legitimate to ask why the military cannot have the same products—like radios, CRT displays, trucks, and clothing—that consumers can go out and buy.)

The problem of getting new technology into the field is not that the United States is unable to develop new technologies with military relevance. It is rather a problem of the transition of that technology into engineering, the time needed to begin manufacture, and the rate at which new systems are built. It can be improved in three general areas: improving the **insertion** of new technology into acquisition programs (i.e., the transition from technology base to engineering and production); improving the **acquisition** process that engineers and produces systems; and improving the **affordability** of systems so that they can be bought more rapidly.

Technology Insertion

The technology development and system acquisition processes are largely (but certainly not completely) separate. Technology base work takes place in a variety of institutions, including some companies that ultimately build systems. Engineering and production are done in private companies (not always the same ones that did the technology base work) under the supervision of DoD program managers. This causes a major bottleneck at the point at which technology moves from technology base to acquisition. Several mechanisms exist to bridge this gap: general technical interchanges between Service lab people and industry; IR&D and contract research that involve some companies in a development; involvement of lab people with the program offices (part of the "smart buyer role"); and formalized Service transition programs.

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[9] In commercial products, complexity is usually the enemy, something to be managed carefully.

Many studies of the transition issue seem to agree that nonsystem-specific prototyping, pursued with 6.3A funds, presents the greatest opportunity to improve technology insertion. It has the potential to solve two problems. By demonstrating feasibility, these advanced technology demonstrations help reduce the high risk carried by some technical developments. And they help correct overoptimism by demonstrating the limitations in the current state of the art. Overoptimism leads to promising too much, which in turn leads to disappointing systems and to lengthy and costly redesign efforts. The new emphasis within DARPA on prototyping is apparently an attempt to ease the transition into system design of technology developed under DARPA programs. DARPA has always been the focus of technology that does not fit neatly into what the Services want to do. However, if the Services do not take DARPA seriously, it is not at all clear that DARPA's prototyping effort will have any use.

Acquisition

In searching for the causes of delays, the acquisition process has been the primary candidate. Even when the system is working smoothly it seems to take a long time to move programs through; but it usually is not working smoothly. And when it bogs down, delays lead to further delays through escalating costs, compensatory stretch outs, and time-consuming attempts to fix any particular program's specific problems. While the consensus is that the system is in trouble, it has weathered study after study without apparent improvement.

Several studies have found that acquisition (advanced development, full-scale development, and production) takes longer than it used to. But the data are not all that clear: there is certainly no obvious trend toward rapidly increasing times. It does take longer in the 1980s than it did in the 1950s or 1960s, but there is not enough data to discern clear trends over the past decade. Studies of fighter aircraft procurement, the most-studied system type, conclude that whatever increases have occurred are in the front-end decision process and in production, not in full-scale engineering development. Data on other systems are less conclusive.

It is generally held that commercial industry completes programs more rapidly than does DoD, but there are significant differences between government and industry that make it possible for industry to avoid many of the basic problems that plague DoD acquisition. These basic problems are "built into the system," they are consequences of the characteristics of U.S. Government. For example, canceling a program that has grown too much in cost or schedule to be profitable is easier than canceling one that, despite schedule slippages and cost overruns, is judged essential for national security.

But enhancing national security is not the Nation's only goal. Goals like fairness, environmental protection, equal opportunity, jobs, and competition all figure into how both Congress and the Administration judge defense procurement programs. DoD itself has goals it must pursue in addition to managing programs efficiently: maintaining the defense industrial base, ensuring that the most efficient producer does not drive the others out of business (contrary to what industry would do), etc. Government is not solely concerned that a program provide the best capability at the lowest cost most quickly. Moreover, the political process in both branches of government—the tug and pull over resources and goals—introduces uncertainty into programs, even when Congress and high-level executive offices do not micromanage programs.

The structure of the DoD acquisition system is much more cumbersome than that of private sector companies. That structure is, in part, determined by government's size and unique role. DoD program managers are accountable to five or six layers of bureaucracy up to the Secretary of Defense. These layers typically have extensive horizontal structure, so the program manager (PM) has to satisfy a large number of people, many of whom have power over his or her program but no responsibility for it. To complicate matters further, the PM reports up one chain for oversight of the program, and up another for the planning, programming, and budgeting system which is responsible for determining the funding for the program. But this involvement of the OSD bureaucracy, as well as that of OMB and

Congress, is part of the checks and balances on the expenditures of billions of dollars.

While industry shares many of DoD's problems, it has a very strong incentive to manage successfully: failure could mean bankruptcy. In many instances industry works under a simpler system involving a direct link between the program manager and a high company official having the authority to make decisions, settle disputes, and insulate the PM from external pressures. The PM has responsibility for the program: if it fails it is his fault and his job may be at stake. The DoD PM typically has to obtain several levels of approval for any action; there are many people who, in trying to ensure that the PM does not fail spectacularly, will also prevent him or her from succeeding spectacularly.

Several factors are major contributors to delays in programs: the sequential processes of requirements generation, resource allocation, and system selection; program variability (or instability) caused by many players making changes; bureaucratic paralysis; inappropriate organization for defense procurement; and the quality and incentive structure for procurement personnel. Underlying these are the basic structure of the government, the nature of the bureaucracy, the organization of the DoD procurement system, and the conservative risk-averse nature of government organizations.

Requirements generation and resource allocation involve the Services, OSD, OMB, and ultimately Congress. They are highly political, which often leads to overpromising in order to get program approval. Overpromising leads to cost growth and schedule slippage. But the system makes it easier to readjust the program to these realities rather than to go back and question the requirements that produced them in the first place.

Constant changes in defense acquisition programs are commonplace, leading to cost increases and schedule slippages. Variability results from the requirements process, the risks inherent in new technology, the political/budgetary process, and personnel turnover. While the disruptions caused by these factors can be somewhat controlled, the underlying causes cannot be eliminated.

Baselining—a form of contract between program managers and their Services—was developed to limit changes in programs. But making baselining work requires giving program managers more authority over their programs than they now have. Neither program managers nor Services can control budgets or other changes and conditions imposed by OSD, OMB, and Congress. Moreover, external factors that affect a program—like threat, doctrine, and resources—will cause changes in the program no matter how well it is managed.

However, Congress, OSD, and OMB can decide to limit their direct involvement in a program (or Congress can decide for the others). But, at least in the case of Congress, this would involve giving up power which it jealously guards. Congress has already agreed, in principle, to relax oversight for a few major acquisition programs, which would require reauthorization only at significant milestones rather than annually. As yet, none of these milestone authorizations have been submitted to, or approved by, Congress. Not all members are likely to agree that efficient functioning of defense acquisition programs is more important than other issues they are concerned with, including the (possibly shifting) interests of their constituents. The budget process specified by the 1974 Budget and Impoundment Control Act and Public Law 99-177 (Gramm-Rudman-Hollings) increases Congress' incentives to keep control of as many budget items as possible so that it can engineer the budget levels it agrees to.

Perhaps the most discussed problem is the bureaucratic burden individuals and companies must struggle through in order to do their jobs. A 1977 Defense Science Board (DSB) panel concluded that increases in acquisition times are all bureaucratic: "it does not take any longer to do something, it just takes longer to obtain the necessary approvals and acquire funding . . . ." The program manager's job has become increasingly complicated, accompanied by lengthening time to complete contracting actions and increased regulation, oversight, and auditing of contractors. The overall perception is that of increasing regulatory and bureaucratic burden, but studies have found the picture to be unclear. While some indicators of burden have been clearly increasing, others have remained the same or declined. Moreover, measuring the effects of regulatory and bureaucratic activity is even more difficult than measuring the activity itself. For example, estimates of the added costs due to regulations and bureaucracy range from 5 to 200 percent!

This "red tape" is unambiguously greater in government than it is in private industry. What in industry can be a straightforward, one-step, project initiation process involving the manager and a high corporate officer is in DoD a two-step process involving the PM, a committee within DoD,[10] and Congress. Both the DSB and the Packard Commission recommended bringing the system closer to an industrial model in this regard, and the Goldwater-Nichols Act tried to implement that.

Since the bureaucratic burden arises in part from government attempts to have programs satisfy goals other than getting the job done most efficiently, solutions can be of two types: those that try to streamline the system without changing its mix of goals; and those that seek to change the balance among goals, particularly the balance between having an efficient and successful program and satisfying all the other government goals. One suggested solution is to review all the regulations to determine whether each is still necessary and whether the aggregate could be streamlined somehow, a daunting task in its own right. Another suggestion is to shift the burden of proof from the PM to those who would slow down the project, making the PM innocent until proven guilty. For example, a competition advocate would have to show that the program was insufficiently competitive or that taking measures to enhance competition was important enough under the circumstances to warrant tampering with the program. But some higher authority would have to be responsible for balancing these claims against the interests of the PM who would always be served by ignoring them.

Some DoD programs do better than most: "black" programs (so it is said), and other special high-priority programs. This success is due in part to their high-priority which affords them high-level attention. Clearly, all DoD programs could not be treated that way or the system would overload. These programs also get special exemptions from various regulations. Granting similar exemptions to all programs would nullify the regulations, defeating the purposes for which they exist.

There has been widespread concern about the process that produces PMs and their chief assistants. These people are either military officers or civil servants. In 1986 the average tenure of PMs was about 2 years. This makes it difficult to give them real power over programs that run many times that long, and creates incentives for them to sacrifice long-term performance in order to look good on their watch. The military personnel usually, but not always, rotate rapidly in and out of the jobs in 2 to 3 years. They do not always have prior experience or relevant training. Many of the civil servants do not rotate, and "remain for so long that they resist innovation and change."[11]

Affordability

One of the major contributors to delays in getting new technology into the field is the cost of modern development and procurement programs and the resultant program stretchouts and low buy rates. Almost all important systems cost enough to get close scrutiny by OSD and Congress. The battles are fought each year. The result is often that the funding requested by the program is reduced (in some cases dramatically), which slows the development pace and slips the date at which production is initiated.

Once the program is in production, DoD's tendency is to reduce the funding below what had been projected, in order to keep as many programs alive as possible. This leads to buying fewer of any particular item per year, which has two major consequences. First, obviously the slower the rate at which a system is bought the longer it will take to get the capability into the field. It may not delay Initial Operating Capability, but it will certainly delay the date at which a significant capability is fielded. Second, providing insufficient funds to procure at planned rates raises the unit costs, which further decreases the number that can be bought per year.

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[10] The Defense Acquisition Board, and perhaps others.

[11] J. Ronald Fox and James L. Field, *The Defense Management Challenge: Weapons Acquisition* (Boston, MA: Harvard Business School Press, 1988), p. 312.

DUAL-USE INDUSTRIES

Most of the technology that is engineered into defense systems is still developed in the "defense world" of DoD's laboratories and contractors. This is particularly true of the exotic technologies that are the centerpieces of advanced designs. But increasingly, building those systems depends on developments that take place in the civilian sector, a civilian sector that is driven by the international marketplace. This was dramatically illustrated by events during the first week of November 1988. A company called Avtex, which manufactured rayon fibers for the apparel industry, announced that it was shutting its doors in response to foreign competition in the clothing business. This sent shock-waves through DoD and NASA when it was discovered that Avtex was the only producer of fibers that were critical to the production of missiles and rockets. While other sources could be qualified, and other fibers might be found to substitute for the rayon that Avtex made, that process would take longer than the period of time the available supply of rayon would support production. Negotiations were soon completed to keep Avtex open.

High-technology industries are becoming increasingly internationalized: foreign companies and multinationals are technology drivers. Large international markets generate huge amounts of capital that fuel research and development into new products and underlying technologies. The defense components of these markets are often small, giving DoD little or no leverage over the directions developments will take. DoD has to choose between playing a follower role, or spending large amounts of money to keep a competitive leading edge capability in defense laboratories and industries. But because of the cost of developing modern technology, it seems unlikely that DoD can afford to develop all the technology it needs in parallel with the civilian sector. Dependence on the private sector is not all bad: commercial development of technology is a basic strength of the industrialized, noncommunist world. Failure to exploit developments in the civilian sector would be throwing away a major advantage over the Soviets. But relying on the private sector means that defense development and production will depend increasingly on the health of the civilian sector and on the ability of DoD and its contractors to gain access to the products of the civilian sector. Thus DoD faces two challenges: maintaining access to the technology developed in the commercial sector, and coping with the international nature of that sector.

DoD and Congress face three generic problems. The first is keeping dual-use companies interested in doing defense work. Some are leaving the defense business. Others have technology that DoD could use, but are reluctant to get into the defense business. These attitudes are based primarily on perceptions of the difficulties of doing business with the government, and the problems of doing business in both sectors simultaneously. Second, high-technology industries are moving offshore due to foreign competition. Some have almost vanished, others are on the way. Furthermore, it seems likely that in the future some new technology-based industries will develop in other nations and never take root here. Careful balance will be necessary to nurture U.S. industries while maintaining access to foreign technology. Congress will have to consider U.S. trade and industry policy carefully. Third, entire industries, individual companies, and the many-stepped trails that lead from raw materials to finished components cross many national borders. In many cases, it is nearly impossible to determine what a U.S. company is, while in others it is difficult to separate U.S. companies from their foreign partners. Congress will have to come to grips with the meaning of foreign ownership and foreign siting for the availability of technology, as well as with how dependent the United States can afford to be on foreign sources. These international relationships will complicate attempts to protect U.S. supply sources.

Barriers Between Civilian and Military Industry

Since World War II, the U.S. economy has evolved relatively separate military and commercial sectors. They have different business practices, one dictated by government regulations and procurement practices and the other flowing from the marketplace. In recent years the *international* market has had a considerable effect on shaping the latter.

Government practices have made it increasingly difficult for DoD to obtain state-of-the-art technology in areas where civilian industries are leading, making defense business unattractive to innovative companies and contributing to traditional suppliers leaving the defense business. Many firms that are not heavily involved in defense business are reluctant to deal with the government because they consider it to be a bad customer. Moreover, many do not need DoD's business and can simply opt out. The barriers are not technological, but legal, institutional, and administrative. Some are the direct result of legislation, others flow from DoD regulations, including overly cautious interpretations of laws. Some commercial firms cite excessive regulation, burdensome auditing and reporting requirements, compromise of trade secrets, and loss of data rights. Large defense companies have similar complaints, but have adjusted to working under these conditions. But for smaller companies, getting into the defense business means heavy investment and reorientation of business practices.

A company can organize to do business in either sector, but can rarely do both under one administrative roof. Companies that do business in both sectors typically have separate divisions that are organized differently and almost never share staff, production and research facilities, data, and accounting procedures. These differences are profound. In large aerospace companies the commercial side responds to market conditions, whereas the military side responds to Service programs, government regulations, and the Federal budget. Their planning is "slaved" to the Federal planning and budgeting cycle. Corporate structures and rules tend to mirror those of DoD and tend to pass government encumbrances down to lower level suppliers. Companies doing government contract work have to keep their books in formats that are compatible with government auditing rules and procedures.

Following these and other government rules adds to the costs of doing business, costs that can legitimately be passed on to the government customer. Tighter control of the defense business ultimately translates into higher costs to DoD. The United States is apparently willing to bear this increased cost as the price of other benefits—for example, knowledge that the government is trying to keep the process honest. However, imposing the same rules on dual-use industries has other, farther-reaching effects. It makes them reluctant to do business with DoD and encumbers their products with additional costs that may adversely affect their international competitive positions. When dealing in both sectors, companies can accept either the higher cost of following government business procedures, or the higher costs of maintaining two separate business practices—one for government business and one for other business. With some exceptions, DoD product specifications are also seen as encumbrances; characteristics that are of no value in the commercial marketplace are engineered into the products for sale to DoD.

Government contracts regulate profits, creating a business environment very different from that in which most high-technology companies deal. These companies are used to investing heavily in R&D, recovering their investments through large profits, and then reinvesting in the next generation of product. Moreover, their customers see only the product, whereas DoD insists on knowing how the product was made. Defense contractors get by on small profits, in part because much of their R&D costs are covered either by contract or IR&D recovery. But dual-use companies qualify for little if any IR&D recovery and are reluctant to do contract R&D. The government owns the rights to data generated by contract R&D so that it can keep the subsequent phases of a project competitive by making a data package available to all bidders. But companies that live by their innovation in the commercial market see this process as offering their trade secrets to the competition. DoD procedures provide the winner of a development contract poor profit margins, no guarantee of a continuing relationship with DoD, and little incentive to innovate and provide a superior product.

Some industries, like advanced composites, are currently so closely tied to the defense business that they are apparently willing to live with these problems. But they worry that their competitive position may be damaged as the commercial market develops. At the other extreme, the companies that produce fiber optics are reluctant to get involved in a defense market they see as always being a small part of their business: they do not necessarily see the potential payoff as worth the aggravation.

While the small amount of military fiber optics business might be seen as evidence that the industry is not really important to defense, some within the DoD see it as a critical new technology for future systems, one in which defense could gain tremendously just by exploiting what has been and is being developed in the commercial sector. But DoD has been generally slow in adopting fiber optic technology. Program managers have much to lose by inserting risky new technologies which may delay schedules and increase costs, but little to gain because the advantages of the substitution will usually become apparent only on someone else's watch.

In the software industry, the divergence between government and commercial practices has been enough to produce separate defense and commercial businesses that often do not share technology. The procedures, policies, and management of large-scale systems in the military and civilian sectors diverge starting with requirements definition, continuing in the development or acquisition of software, and throughout the entire life cycle of the software. This restricts the flow of leading-edge technology from defense into the commercial sector and reduces DoD access to readily available commercial products. Most of the differences can be attributed to the policies, regulations, standards, and directives mandated by DoD. DoD software requirements are more rigid than their commercial counterparts. Defense systems tend to be overwhelmingly custom built, while commercial systems will use as much off-the-shelf technology as possible. Software companies are particularly concerned about data rights, which they see as critical to competitiveness. Companies are reluctant to deal under DoD restictions; in their eyes the government would be taking and possibly giving to their competitors the very basis of their business.

International Competitiveness and the Health of U.S. Industries

The Department of Defense has been concerned for some time about the implications for defense of deteriorating competitive positions of U.S. manufacturing companies in the international market.[12] The government is also concerned from a wider perspective that this trend is weakening and undermining the U.S. economy. DoD shares the concern that a weakening economy and a drain of resources into purchases of foreign goods will reduce money available to produce defense equipment, but its primary concern is the continuing availability of necessary items and technology.

The government does not as yet have a policy regarding dependence on foreign sources for defense material and technology, let alone a game plan for implementing such a policy. The Undersecretary of Defense for Acquisition has recommended a plan to bolster defense-related manufacturing in the United States.[13] The report detailing that plan does not make a statement on how much foreign dependence is tolerable, although it does imply that some is unavoidable.

The complexity of the problem is illustrated by the issue of cooperative development and production of defense equipment with the European NATO Allies. It has been long-standing U.S. policy to encourage multinational procurement of similar defense equipment to foster commonality, to get the best equipment into the forces of all the Allies, to save money, and recently, to exploit a broad multinational technology base. In recent years the Defense Department has made great progress in generating international memoranda of understanding for joint development, with the help of initiatives like the Nunn Amendment. But as the Europeans have become more interested in cooperative developments, they have also sought a greater share in generating the technology and a larger market share for their defense industries. Interest by U.S. companies in joint ventures with Europeans has been spurred, in part, by fears that several trends in European thinking could sharply curtail their sales in Europe. Thus, the cooperative programs are a two-edged sword helping U.S. sales in Europe while stimulating European sales to the United States; and helping U.S. defense policy in general, while both helping and hindering the maintenance of the U.S. defense industrial technology base. Crafting a workable policy will be a tricky job.

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[12] For examples, see Defense Science Board, "Report of the Defense Science Board Task Force on Defense Semiconductor Dependency," prepared for the Office of the Under Secretary of Defense for Acquisition, February 1987; Report to the Secretary of Defense by the Under Secretary for Acquisition, "Bolstering Defense Industrial Competitiveness: Preserving Our Heritage, the Industrial Base, Securing Our Future" (Washington, DC: Department of Defense, 1988); and Martin Libicki. *Industrial Strength Defense: A Disquisition on Manufacturing, Surge, and War* (Washington, DC: National Defense University, 1986). See also, U.S. Congress, Office of Technology Assessment, *Paying the Bill: Manufacturing and America's Trade Deficit*, OTA-ITE-390 (Springfield, VA: National Technical Information Service, June 1988).

[13] See "Bolstering Defense Industrial Competitiveness," op. cit., footnote 12.

There are three basic policy choices:

- demand that anything that goes into defense equipment be built in the U.S. from U.S.-sourced components, taking whatever measures are necessary to ensure that all the necessary industries are alive and well in the United States;
- let the market dictate which industries will be healthy in the United States and look only for the best deals wherever they can be found worldwide; or
- choose some industries that have to be located in the United States, take appropriate measures to ensure that, and let the rest go with the market.

The first and third require some sort of intervention in the international economy, either supporting the international competitiveness of U.S. companies or protecting, supporting, and subsidizing U.S. companies that cannot otherwise survive. Another approach is to design nothing into U.S. defense systems that cannot be domestically sourced. But this cuts off a great deal of modern technology, a Western strength. In making these choices, the United States will have to decide how dependent we can afford to be, and how much independence we are willing to pay for. If the United States demands self-sufficiency without taking measures to keep U.S. companies alive and competitive, the list of technologies available for defense systems is likely to decrease as time goes on.

It will be necessary to decide how to treat dependence on various nations. There are significant differences in being dependent on Canada (already defined as part of the North American industrial base), Britain, our other NATO allies, Mexico, Japan, Korea, etc. U.S. and Canadian companies are closely intertwined. Despite the recent controversy over the trade agreement and other arguments, we are each other's largest trading partners. Canada is also a NATO ally with a common security interest. The chances of being cut off from Canadian sources either by policy or by hostile act are minimal. We are also close to our European Allies; much of our defense equipment is bought to defend them. But we are separated from Europe by an ocean, and they have not always supported U.S. military actions. Other nations are much less tightly tied to the United States.

The high-technology economy is an international one and responds to international market forces. These forces are likely to continue to move industries offshore despite U.S. efforts to will (or legislate) them to stay. In the vast majority of cases, defense business is far too small to provide the necessary clout, particularly when faced with other nations that manipulate their civilian markets to keep their companies healthy. Competition comes from Japan, the smaller Asian nations—Korea, Taiwan, Singapore, etc—and Western Europe. The Europeans are taking dramatic steps to improve their international competitive position, particularly in high technology industries. These include the economic integration of the EC in 1992, and the funding and encouragement of large cooperative R&D projects.

Although all industries are different, the plight of the fiber optics industry is illustrative. While healthy in the United States, it faces increasingly stiff competition at home and continuing difficulties abroad stemming from limited access to foreign markets. Both the Europeans and the Japanese are making major pushes in fiber optics and photonics in general. U.S. technology and production costs are at least competitive. But while U.S. producers have been largely excluded from some important foreign markets, the U.S. market remains open to foreign vendors. Japanese companies can sell in foreign markets at low prices because their government has discouraged foreign competition in Japan where prices are kept artificially high. The closed domestic market supports overseas competitiveness.

The U.S. software industry faces a different sort of challenge. It is currently strong and competitive, but the rapid growth in worldwide demand for software threatens to outstrip the capacity of U.S. firms to meet it, leaving a large opening for foreign firms to penetrate the market. Japan, France, the United Kingdom, Korea, Singapore, Taiwan, and India have the capacity to penetrate the global market. And many of these nations have trade policies that either discourage sales by U.S. companies or fail to protect the intellectual property rights of those companies: "pirated" software is becoming a major problem. Moreover, the Japanese are making rapid strides in turning software design from art to manufacture, building software factories to increase productivity dramatically.

Internationalization of Industries

Efforts to protect and nurture U.S. companies will be complicated by trends toward internationalization in high-technology industries. Examples are found in the advanced composites industry in which many of the firms that appear to be American—because they have American names or U.S. facilities—are actually owned by foreign companies and in the fiber optics business where international joint ventures are used to get into otherwise closed markets. International ownership, vertical and horizontal integration, and international siting make it difficult to define in any convincing way what an American company is. Moreover, the sequence of steps that leads to a final product often crosses international boundaries many times and shifts as prices and availability of components shifts. Is a Pontiac built in Korea any more or less an American product than a Honda made in the United States or a Chevrolet/Toyota assembled in California from U.S. and Japanese parts?

Difficulties in identifying U.S. companies will produce difficulties in writing legislation to protect them or establishing DoD policy to encourage the growth of important domestic industries. Foreign plants owned by U.S companies, U.S. plants owned by foreign companies, joint ownership, and joint ventures all offer different sets of problems.

Formulating Policy

These trends toward internationalization will complicate difficult issues that Congress and the Administration are already facing. Paramount among these is to decide whether the U.S. Government will play a major role in encouraging and supporting U.S. commercial business and industry, or whether—almost unique among the governments of major nations—it will continue to remain more or less aloof, confining its activities to a few international trade negotiations. Other governments encourage the development of commercial technology and associated industry, help to foster a domestic situation conducive to growth, and support aggressive overseas marketing.

Having decided government's role, the next issue would be to define goals. These might include:

- keeping key nondefense manufacture and development in the United States,
- keeping manufacture and development in the hands of U.S.-based (or U.S.-owned) companies;
- preserving some portion of the U.S. market for U.S.-based (or U.S.-owned) companies; and
- gaining access to foreign markets for U.S. firms.

Defining such goals will entail arriving at a working definition of a U.S. company, or at least of how location and ownership affect U.S. national security interests.

It would be necessary to decide how large a role defense needs would play in deciding which industries are in need of government attention. This decision would have to balance the problems of foreign dependence against the risk of diminished access to foreign technology and manufacture. It would also have to consider how much the United States is willing to pay to buy domestically that which may be available at a lower price elsewhere. The lessons of "low-priced oil" from the Persian Gulf are instructive here. Determining the acceptable degree of offshore dependence for defense equipment will necessitate deciding the level of componentry which DoD would have to specify as coming from domestic sources. For example, is it sufficient to require that systems or subsystems be domestically sourced, or does DoD have to assure that some or all of the components are made in the U.S.A.? This decision would dictate the level at which DoD would need visibility into the manufacturing process and have to keep a data base on suppliers.

Whatever the goals are, Congress will have to decide what levers can be pulled to make those attainable. In most cases, simply controlling defense procurement will not be enough to influence the industry: it may ultimately lead to an inefficient, backward, protected industry that is incapable of competing on the world market. Such an industry might only be capable of providing DoD with obsolete technology or overpriced products. The government has the option of getting more deeply involved in stimulating the development of technology for commercial ends, including making government R&D facilities more available and providing greater incentives for corporate investment. Yet another option is to formulate a strategy—as Japan and other nations have—for controlling access to critical U.S. commercial markets in order to preserve and support domestic industrial capabilities. A third policy lever that can be manipulated, but not totally controlled, is the cost and availability of capital for conducting R&D. Major technological developments are capital intensive, with costs measured in the hundreds of millions to billions of dollars. European and Japanese companies pay less to borrow money than do U.S. companies—far less in the case of the Japanese. This allows them to carry on more projects simultaneously, and to sell the resultant products at lower prices than those of their U.S. competitors, putting U.S. companies at a competitive disadvantage.

Chapter 4

Planning and Funding DoD Technology Base Programs

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Chapter 4

Planning and Funding DoD Technology Base Programs

INTRODUCTION

In today's technology-intensive environment—in both the military and commercial context—the ability of an organization to compete and win is highly dependent on its ability to discover, develop, and apply advances in science and technology to its systems and products. Success in that endeavor depends, in turn, on the ability of the organization to plan its technology investment strategy, marshal the resources to support it, and build and sustain a technology base vital enough to produce the needed advances.

The development and management of the technology base underlying defense systems is an exceedingly complex enterprise. It is as multifarious—and as important to national interests—as the capabilities and performance of the defense systems themselves. This chapter examines the Department of Defense (DoD) system for managing its technology base programs. It reviews how the Office of the Secretary of Defense (OSD)—particularly the Office of the Director of Defense Research and Engineering (ODDR&E)—carries out its technology base oversight responsibilities. **The purpose of this chapter is to evaluate the ability of the present OSD technology base management system to do its job, and not to judge the performance of any Administration or individual DoD officers. It focuses on oversight activities such as strategic planning and coordination of technology base programs—that is, on the role of OSD in planning the programs of the Services, defense agencies, and the Strategic Defense Initiative Organization (SDIO), and forming them into a coherent whole—and not on the management of specific technology base program elements (PEs).**

These oversight responsibilities include: 1) developing an overall technology base investment strategy; 2) setting research priorities and directions; 3) reviewing and evaluating the technology base program goals; 4) coordinating the numerous research activities that make up DoD's technology base programs; 5) acting as an advocate for the technology base programs; and 6) evaluating the outcomes and effectiveness of DoD-sponsored technology base activities.

The next section of this chapter briefly describes[1] the activities that comprise DoD's technology base programs and how OSD, the three Services, the Defense Advanced Research Projects Agency (DARPA), and the SDIO[2] are organized to manage and implement their technology base programs. The following section then reviews how OSD, the three Services, and DARPA fulfill their respective technology base management responsibilities.

The second major portion of the chapter examines issues associated with the way in which OSD is organized to carry out its technology base oversight activities. The chapter concludes with a discussion of the support within DoD for its technology base programs, including an analysis of past and current technology base funding trends.

HOW THE DEFENSE DEPARTMENT MAKES AND IMPLEMENTS TECHNOLOGY POLICY

Although the Department of Defense will invest less than 4 percent of its entire budget in technology base activities in fiscal year 1989 (see table 1), many observers inside and outside the Pentagon consider DoD's technology base programs to be a crucial investment in the Nation's overall security. The military's technology base programs represent a wide spectrum of "front-end" technology development, beginning with a broad base of basic research support and extending through the demonstration of technology that might be applied in future defense systems. The scope of DoD's technology base

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[1] For a more detailed discussion of how OSD and the Services organize their respective technology base programs, see the March 1988 OTA report entitled *The Defense Technology Base: Introduction and Overview—A Special Report*, OTA-ISC-374 (Washington, DC: U.S. Government Printing Office).

[2] For further information on the SDI program, see Library of Congress, Congressional Research Service, "The Strategic Defense Initiative: Program Description and Major Issues," CRS Report No. 86-8 SPR, 1986.

Table 1—Department of Defense Funding of Technology Base Programs, Fiscal Year 1989
(in millions of dollars)[a]

	Army	Navy	Air Force	DARPA	Category total[b]
Research (6.1)	$173	$355	$196	$88	$956
Exploratory Development (6.2)	$561	$431	$574	$624	$2,522
Advanced Exploratory Development (6.3A)	$422	$193	$764	$557	$2,099
Service or agency total	$1,156	$979	$1,534	$1,269	$5,577
Strategic Defense Initiative					$3,606
Total: DoD technology base programs					$9,183

[a] Appropriated.
[b] Category totals also include funding for the other defense agencies and University Research Initiatives program.

SOURCE: Office of the Secretary of Defense.

programs includes such diverse concerns as meteorology technology and the technologies for autonomous guided missiles capable of differentiating among various targets.

DoD organizes its technology base programs into three budgetary categories: research (funded under category 6.1); exploratory development, the practical application of that research (budget category 6.2); and advanced exploratory development, which primarily consists of the building of prototypes to demonstrate the feasibility of applying a particular technology to a weapon system (budget category 6.3A). Work funded under the remainder of the Department's budget for research, development, test, and evaluation (RDT&E), representing about 80 percent of the RDT&E budget, is not considered to be part of the technology base.[3]

DoD's complex technology base program is planned, organized, and implemented by the three Services (Army, Navy, and Air Force), DARPA, the other defense agencies, and the SDIO, with the oversight and guidance of the OSD. The largest portion of the technology base program is conducted outside DoD by industry (50 percent) and universities (20 percent), with DoD in-house laboratories conducting the remaining 30 percent.

In the last three years, each of the three Services and OSD have reorganized the management of their technology base programs. As a result of the Goldwater-Nichols Act, the position of Under Secretary of Defense for Acquisition [USD(A)] was established and given responsibilities for all RDT&E activities except for those of the SDIO. The Director of SDIO reports directly to the Secretary of Defense (see figure 2). The Goldwater-Nichols Act also reestablished the DDR&E as the primary individual responsible for DoD's technology base activities. The DDR&E is responsible for assuring the appropriate emphasis and balance for DoD's entire technology base program, except for SDIO.

Once the Services—the Army, Navy, and Air Force—have formulated their technology base programs, the Deputy DDR&E for Research and Advanced Technology [DDDR&E(R&AT)] has the task of ensuring that their proposals have responded to OSD guidance. The Deputy for R&AT serves as "the corporate guardian" of the technology base programs, ensuring that the Services' programs are well balanced, with little duplication of effort, while attempting to meet the current and future scientific and technological needs of DoD. The Services' technology base programs are coordinated with DARPA's programs at the next level, the DDR&E. Finally, conflicts among these four programs and SDIO are adjudicated only at the highest level, the Secretary of Defense.

Each of the Services conducts an extensive annual top-down, bottom-up planning exercise. From the top, the Services receive OSD's annual Defense Guidance document, which provides them with guidance on developing their overall RDT&E programs. Planning begins with a review and

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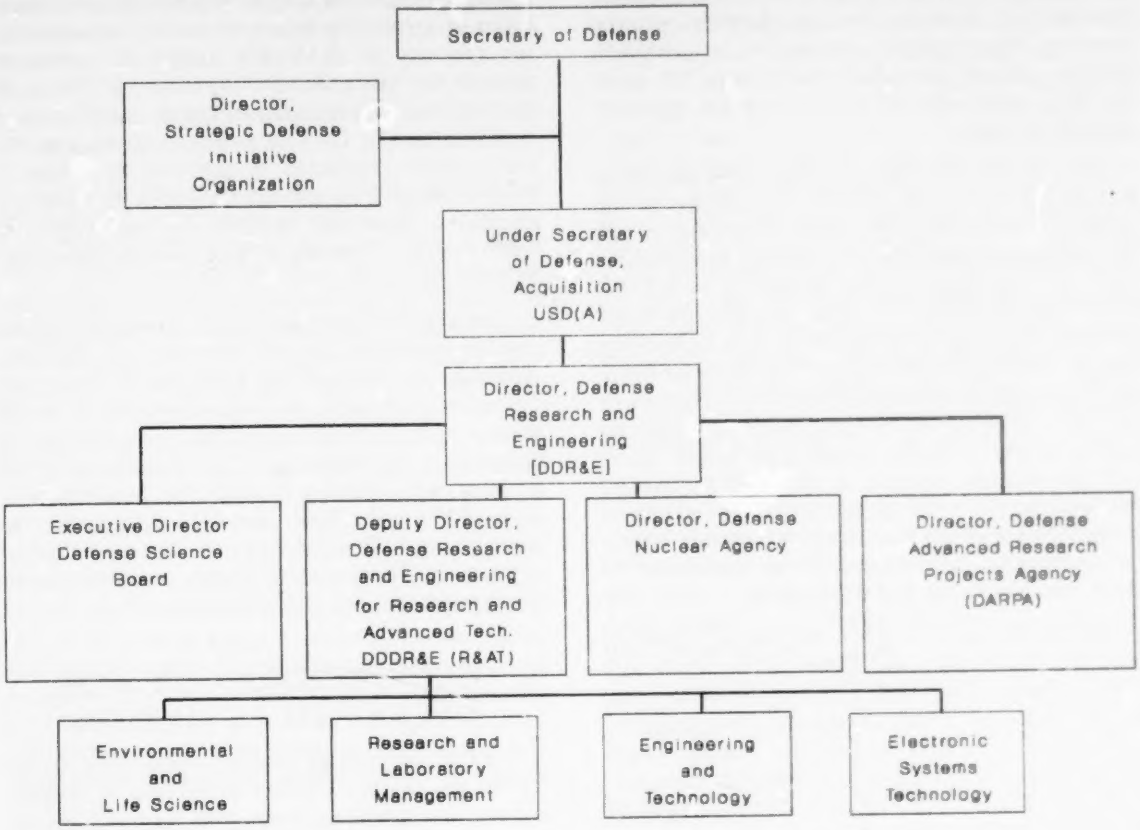
[3] DoD typically considers 6.1 and 6.2 as its "technology base programs," with 6.1 through 6.3A normally referred to as its "science and technology programs." However, in recent years these distinctions have become blurred in everyday usage. This report uses both terms to refer to budget categories 6.1, 6.2, and 6.3A.

Figure 2—Management of the Department of Defense Technology Base Program


Secretary of Defense
Director, Strategic Defense Initiative Organization
Under Secretary of Defense, Acquisition USD(A)
Director, Defense Research and Engineering [DDR&E]
Executive Director Defense Science Board
Deputy Director, Defense Research and Engineering for Research and Advanced Tech. DDDR&E (R&AT)
Director, Defense Nuclear Agency
Director, Defense Advanced Research Projects Agency (DARPA)
Environmental and Life Science
Research and Laboratory Management
Engineering and Technology
Electronic Systems Technology

SOURCE: Office of Technology Assessment, 1989.

evaluation of the previous year's research activities. When this review is completed, the Services then decide which activities to continue, which to transition from 6.1 into 6.2 or from 6.2 into 6.3A programs, which to move beyond 6.3A, and which activities to end.[4]

Each of the three Services operates and manages its technology base activities differently. Compared to the other two, the Army employs a less centralized approach, relying on major field commands—the Army Materiel Command (AMC), the Corps of Engineers (COE), and the Surgeon General (TSG)—as well as the Deputy Chief of Staff for Personnel (DCSPER), to help develop and implement its technology base investment strategy. Compared to those of the Navy and Air Force, the Army's technology base headquarters staff is quite small. The Deputy for Technology and Assessment (DT&A) is considered to be the Army's Program Executive Officer (PEO) for the technology base programs. The DT&A is responsible for coordinating the technology base programs of AMC, COE, TSG, and the DCS for Personnel. The Army's Laboratory

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[4] Transitions may actually occur at times from 6.1 or 6.2 to 6.3, 6.4 or even directly to operational systems.

Command (LABCOM) is responsible for overseeing and managing 75 percent of the Army's technology base program, including its eight laboratories, seven research, development, and evaluation (RD&E) centers, and the Army Research Office. The commanding officer of LABCOM reports to the commander of AMC.

Of the three Services, the Navy has placed its technology base management institutions at the farthest remove from its procurement institutions. But relevance to Navy needs still remains a powerful factor in selecting projects, especially in 6.2 and 6.3A. Further, unlike the other Services, the Navy performs the majority (60 percent) of its technology base programs in-house. Many of the Navy laboratories are capable of performing the entire spectrum of RDT&E activities. The Navy supports the oldest and largest of the Services' research programs, along with the smallest program in advanced technology demonstration. The Navy claims to be rebuilding its advanced exploratory development program, which, unlike the other Services, it does not manage in the same office as its 6.1 and 6.2 programs.

As of November 1, 1987, the Deputy Chief of Staff for Technology and Plans (DCS T&P), Air Force Systems Command, was established to oversee the entire Air Force technology base program. The DCS T&P is also the PEO for, and the single manager of, the Air Force's technology base program. The Air Force Chief of Staff has designated the technology base program as a "corporate investment" to help raise its visibility and to provide a long-term, stable funding base for the program. The Air Force operates the largest extramural technology base program of the three Services. Its technology base activities are more centralized than are those of the other Services. The Air Force places special emphasis on technology insertion: It has the largest advanced exploratory development program; and its laboratories are more closely linked to its five major systems divisions than those of the other Services are to theirs.

The role of DARPA appears to be changing with the recent establishment of its Prototyping Office. DARPA was originally established to support high-risk, long-range research. It does not operate laboratories or conduct in-house research. Consequently, the majority of DARPA's budget is contracted through the three Services to industry (75 to 80 percent) and universities (20 percent), with only a small fraction of DARPA's technology base activities actually conducted by the military. There is some concern that allowing DARPA to enter the domain of hardware development and prototype testing might compromise its support of long-range, high-risk research.

The SDIO program is centrally managed, with its director reporting to the Secretary of Defense. Although the entire SDIO budget is funded under 6.3A, DoD estimates that approximately 15 to 20 percent of the SDI budget is spent on research and exploratory development. The majority of SDI projects are executed through the Services with some additional efforts through other executive agencies, including DARPA, the Defense Nuclear Agency, the Department of Energy, and the National Aeronautics and Space Administration.[5]

OSD'S TECHNOLOGY BASE OVERSIGHT ACTIVITIES

The DoD technology base programs play a crucial role in the military's ability to develop technology and apply it rapidly to meeting the Nation's security needs. DoD reports that its science and technology capabilities continue to improve, but the technological lead over potential adversaries is shrinking. One way for DoD to counter this adverse trend is to make sure that its technology base programs are planned, managed, and executed as effectively as possible.

Developing a Technology Base Investment Strategy

DoD does not have an overall, coordinated technology base investment strategy or plan to establish science and technology (S&T) priorities. According to a recent report by the Institute for

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[5] This chapter does not examine the research activities of several smaller agencies within DoD which account for less than 2 percent of RDT&E. Those agencies include: the Defense Mapping Agency; National Security Agency; Defense Nuclear Agency; Defense Support Project Office; Defense Communications Agency; Defense Intelligence Agency; Defense Logistics Agency; and the Uniformed Services University.

Defense Analyses (IDA),[6] a significant amount of long-range planning is taking place in the Services, the research and development (R&D) centers, and DARPA, but "these efforts are, at the moment, pursued independently within each of the Services and, to some degree, independently at the R&D center (laboratory) level."[7]

Many observers within the military believe that technology base planning should remain decentralized.[8] The Services assert that they have a much better understanding of their respective combat needs than does OSD. As a result, the Services—not OSD—possess the knowledge and technical skills necessary to establish a rational technology base investment strategy to meet future combat needs. Many analysts believe that any attempt to centralize planning for the technology base programs within USD(A) would be unsuccessful. Representatives of the Services and DARPA argue that OSD's primary role should be as advocate, reviewer, and coordinator for DoD's technology base programs. In this view, USD(A) should make sure that the technology base is clearly understood within OSD, that Service and DARPA programs are reviewed for adequacy, and that unwarranted program duplication between the Services is avoided. Advocates of this view also hold that OSD is less able to defend the technology base budget than are the Services, and greater OSD involvement would result in less Service support of the technology base.

On the other hand, the report of the IDA task force does not endorse these beliefs. The task force recommended that OSD adopt a strategic planning process to "tie together the investment strategies as they currently exist in the Services and Agencies."[9] This strategic planning activity would involve OSD working *with* the Services, the defense agencies, and SDIO in order to establish technology base goals and priorities. It does not imply the creation of an OSD "planning czar" who establishes goals and objectives for all of DoD's technology base programs. The IDA report notes that strategic planning, in any organization, will not succeed if it fails to involve an adequate number of the right people. In this approach, once a coordinated technology base investment strategy has been developed, the actual planning and execution of the various programs could continue in the current decentralized fashion. As in the past, the Services and DARPA would be responsible for organizing and executing their technology base programs. However, the DDR&E would be in a position to evaluate each agency's program, based on how well it responded to the priorities established during the strategic planning process.

The Services and DARPA assert that the annual Defense Guidance document—supplemented with additional Service requirements documentation—provides adequate planning guidance to develop their respective technology base investment strategies. However, many other observers criticize the Defense Guidance on the ground that it is developed through a fragmented process which fails to produce a coherent, well-coordinated U.S. defense posture. The document is prepared by the UnderSecretary of Defense for Policy, based on Administration guidance and inputs from the Joint Chiefs of Staff, the Unified and Specified Commands (CINCs),[10] the Service Secretaries, other OSD Staff (including the DDR&E), and other relevant sources. Once the Guidance is approved and published, the Services use it to build their respective programs, including their science and technology programs. There are also various inter-Service requirements documents that help to gear technology to future defense needs.

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[6] Task Force Report, "The Improved Coordination of DoD Science and Technology Programs" (Alexandria, VA: Institute for Defense Analyses, July 1988). At the request of the DDR&E, IDA assembled a task force consisting of numerous S&T managers from the Services and OSD to examine approaches for improving coordination of DOD's technology base programs.

[7] The Services have conducted impressive technological forecasting activities, including the Air Force's Forecast II study, the Navy's 21 study, and the Army's proposed Strategic Technologies for the Army (STAR) study. Such studies have been used to establish S&T priorities in the Services. However, as the IDA Task Force indicated, these activities are primarily pursued independently within each Service.

[8] Institute for Defense Analyses, op. cit., footnote 6, p. 3.

[9] Summary Report and Recommendations of the IDA Task Force on Improved Coordination of the DoD Science and Technology Programs (Alexandria, VA: Institute for Defense Analyses, July 1988), p. II-2.

[10] A unified command, composed of significant forces from two or more Services, has a broad, continuing mission (usually geographically based). A specified command, composed primarily of forces from one Service, has a functional mission. The eight unified commands are Europe, Pacific, Atlantic, Southern, Central, Special Operations, Transportation, and Space. The specified commands are the Strategic Air Command, Aerospace Defense Command, and Military Airlift Command. The names of the commands designate their primary geographic or functional area of responsibility. Central Command, created in 1983, is concerned with the Persian Gulf region.

Nevertheless, the current 120-page document provides only one page of guidance for the DoD-wide technology base programs. More could help generate a stronger technology base program. Such broad guidance allows the Services and DARPA to justify technology base programs that they view as being in their individual best interests, but which may or may not meet the overall future science and technology needs of the Department of Defense as a whole.

In the absence of a centralized S&T investment strategy, it is extremely difficult for the DDR&E to assess the technology base programs of the Services and DARPA, other than for technical merit. The 1983 Grace report indicated that planning which permits the bottom-up approach to predominate—the current situation—often results in duplication of effort, and ineffective coordination of science and technology programs.[11] OSD's technology base investment review is primarily an information gathering function. When the Services present their annual technology base investment strategy to the DDDR&E(R&AT), no formal written feedback is provided, although there are usually verbal comments. Until this year, each of the Service's programs was reviewed separately, making cross-Service comparisons difficult. The Defense agencies (primarily DARPA) are not required to participate in this process, although they usually do to a limited extent.

Under current conditions, OSD cannot ensure that DoD's technology base programs are well balanced, properly coordinated, and capable of meeting the current and future science and technology needs of DoD. On the other hand, it is clear that OSD would be unable to conduct an effective technology base investment strategy without the close cooperation and goodwill of the Services and DARPA. Because the Services currently dominate the planning process, and act independently of one another, any effort to consolidate this function in OSD could cause dislocation and disruption of existing technology base program management.

Establishing Research Priorities and Direction

The dominant position of the Services in determining technology base initiatives arises from, and contributes to, the lack of an overall technology base investment strategy. The Services have filled a power vacuum and now protect their power. Instead of working with OSD to establish priorities based on overall defense needs, the Services allocate resources based on their own views of their individual needs. A 1981 Defense Science Board study recommended that a DoD R&D investment strategy linked to future combat needs be utilized in technology base planning "... so that technologies funded through the allocation processes would be more explicitly and consistently related to future operational needs."[12]

In the absence of broad strategic guidance, individual Service goals tend to supplant more general strategic ones. As the primary civilian component within DoD, the Office of the Secretary of Defense is supposed to act as a counterbalancing force to the Services, working objectively with the Services and DARPA to develop an overall technology base strategy in the best interest of DoD as a whole. In principle, once the strategy is articulated, the Services and DARPA develop science and technology goals to achieve that strategy.

The implications of inadequate OSD guidance can be significant with regard to the types of technological priorities the Services are willing to support. For example, according to Samuel P. Huntington,[13] the Services are extremely reluctant to support "orphan" functions that are not central to a Service's own definition of its mission or fighting doctrine. This can present great difficulties for setting well-balanced science and technology priorities, since modern technology has provided capabilities that may not coincide with traditional approaches to mission accomplishment or to the accepted division of mission responsibility.

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[11] "President's Private Sector Survey on Cost Control," report of the Task Force on Research and Development, Executive Office of the President, Dec. 8, 1983, p. 30.

[12] U.S. Department of Defense, Office of the DDR&E, "Report of the Defense Science Board, 1981 Summer Study Panel on the Technology Base" (Springfield, VA: National Technical Information Service, November 1981), p. i-2.

[13] Samuel P. Huntington, "Organization and Strategy," in *Reorganizing America's Defense* (Washington, DC: Pergamon Press, 1985), p. 236.

The Services are often reluctant to support technology base initiatives that challenge their current mission or fighting doctrine, and because they dominate the technology base planning process, they are in a position to discourage such initiatives.

Coordination of Technology Base Programs

DoD lacks a strong and focused coordinating capability for its science and technology programs. Although DoD has over 200 tri-Service and interagency coordinating groups, in general they have not been effective at providing high level coordination across the DoD-wide technology base programs. (However, some, such as the Joint Service Electronics Program [JSEP], have produced impressive results.) Coordination efforts are further hampered because a significant portion of DoD's science and technology programs are not under the direct purview of the DDDR&E(R&AT).

In its task force report on improved coordination of DoD S&T programs, the Institute for Defense Analyses concluded that it is necessary to differentiate between "technical interchange" and "programmatic coordination." The IDA study concluded that currently there is much technical interchange among the Services, but very little programmatic coordination is aimed at identifying scientific or technological gaps and overlaps. The IDA study states that, without proper coordination, it is difficult to ensure that the total DoD S&T program is properly addressing the overall science and technology needs of DoD.[14]

OSD uses annual science and technology reviews to help evaluate and improve the coordination of its technology base programs. These reviews are designed to examine a particular technology base program element (PE)[15] (e.g., avionics) and the projects in that element. However, such reviews are not always effective. Due to manpower constraints, OSD can only conduct a limited number of S&T reviews each year. Further, since there is no uniform OSD-wide format for conducting the reviews, the methodology and thoroughness vary greatly. With over 200 coordinating groups producing a hodgepodge of different reports, it is very difficult for OSD to determine whether the resources of its technology base program are being allocated wisely.

The IDA task force made three major recommendations for strengthening science and technology coordination. The first is to establish a DoD-wide S&T Coordinating Group responsible for establishing 17 Technology Coordinating Panels (TCPs) for the entire S&T program. Membership of the TCPs would consist of senior R&D managers from the Services, the agencies including DARPA, and SDIO.

The TCP panel members would be kept up to date on the status of a particular technology, the justification for specific programs in which a technology is used, and why the users' needs necessitate the pursuit of that technology. The purpose of the TCP panels would be to reduce unwarranted technology duplication, ensure that resources in a particular technology area are well balanced, identify potential technology gaps, and identify critical long-lead-time technologies in a series of annual reports.

The second major recommendation is that OSD, the Services, the agencies, and SDIO develop a DoD-wide format for the annual TCP reports. DoD currently has no formal S&T reporting process for its 200 coordinating groups. If these 17 TCP groups are to be effective, IDA believes, they should produce consistent reports that outline important technology activities across all of DoD's S&T activities.

The third, and final, recommendation is to absorb and disband those existing coordinating groups that are not needed to support the work of the TCPs. IDA points out that each of the 17 TCPs would have under it a number of (existing) technology coordinating subgroups. For example, the TCP for Ships and Submarines would have three subgroups: Hulls, Hydrodynamics, and Machining. Each of the subgroups would be required to contribute to the TCP's annual report. Those not needed for this process would be disbanded.

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[14] Institute for Defense Analyses, op. cit., footnote 6, p. 3.

[15] The PE is the basic building block in DoD's program planning and budgeting system (PPBS). There are approximately 180 PEs in DoD's entire technology base program, with each PE consisting of all costs associated with a research activity or weapon system.

Although these recommendations might help to improve technology base coordination, getting them accepted and implemented within DoD may prove to be difficult. Each of the recommendations would have to be approved by the DDR&E as well as the USD(A) and then implemented by the Services and the defense agencies. This is a process which in the past has proven to be very difficult. For example, although DARPA was invited to participate in the IDA study, no DARPA representatives attended the meetings of the task force or participated in writing the final report.

Distrust and misunderstandings among OSD, the Services, and DARPA are a major impediment to improving S&T coordination. Efforts by OSD to improve cooperation or coordination can be interpreted as an attempt to tell the Services and DARPA how to manage their science and technology programs. Some OSD representatives believe that the Services will pursue an independent path when possible. Accordingly, improved coordination among OSD, the Services, DARPA, and SDIO will be difficult to achieve.

Acting as a Strong Advocate for DoD's Science and Technology Programs

OSD currently lacks a strong defender of its technology base programs. A strong advocate would have two primary responsibilities: 1) presenting a comprehensive review and defense of DoD-wide technology base programs to Congress; and 2) acting as a strong proponent for the S&T programs within the DoD.

The IDA task force concluded that there is no single individual within OSD who is responsible for presenting and defending technology base programs before Congress or within DoD. The task force indicated that the USD(A) should provide high-visibility advocacy for the S&T programs and develop a coherent DoD-wide position statement on the technology base programs.[16]

The lack of an effective S&T advocate within OSD has contributed to the erroneous perception, in Congress and even within DoD, that the technology base programs have shared in the rapid growth of the RDT&E account. Between fiscal years 1984 and 1989, funding for DoD's RDT&E programs increased 20 percent in constant dollars (see table 2). During the same period, however, research (6.1) and exploratory development (6.2) funding declined 3 percent and 6 percent, respectively, in constant dollars. Between fiscal years 1984 and 1989, almost all of the growth in DoD's S&T programs can be attributed to SDI. When the SDI figures are included in DoD's S&T activities, they present a distorted impression of budgetary growth in the S&T programs. The DDR&E testified before Congress that the rapid growth of the SDI budget has strengthened the technology base programs of DoD. By contrast, IDA task force members expressed the belief that most SDI efforts have been of little use to the rest of DoD's S&T programs.

In recent years, OSD has been unable to present a comprehensive review of its technology base programs to Congress in a compelling way. For example, in DoD's fiscal year 1987 RDT&E report to Congress (the last year DoD produced such a report), all the major RDT&E goals were focused on short-term objectives. The report did not make adequate distinctions between technology base activities on one hand and development, testing, and evaluation activities on the other. OSD failed to connect technology base advancements with the development of current and future weapon systems. Finally, the report provided no information on how funding trends for technology base programs compared with the overall growth in RDT&E funding.

In some cases, OSD officials have not been able to prevent the Services from shifting funds away from their own S&T programs in order to support more immediate concerns such as procurement, or to prevent OSD from cutting technology base programs. This is clear in budget reviews, and was demonstrated recently when the Army cut funding for its research program by almost one-third and cancelled its In-House Laboratory Independent Research (ILIR) program.

As illustrated by table 3, the Army—like the other Services—supported consistent increases in its research program beginning in fiscal year 1980. However, in fiscal year 1987, when DoD faced budget constraints, the Army cut its research pro-

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[16] Institute for Defense Analyses, op. cit., footnote 6, p. 9.

Table 2—DoD Technology Base Funding, Fiscal Years 1984 Through 1989 (millions of 1982$)

	1984	1985	1986	1987	1988	1989	% Change (constant $) 1984-1989
Basic Research (6.1)[a]	778	760	831	756	740	755	-3
Exploratory Development (6.2)	2,051	2,032	1,984	1,985	1,924	1,928	-6
Advanced Technology Development Without SDI	1,261	1,175	1,223	1,433	1,438	1,408[b]	12
SDI office	1,109[c]	1,243	2,318	3,156	2,957	2,849	157[d]
Total Technology Base With SDI	5,199	5,210	6,356	7,330	7,059	7,191	38
Total Technology Base Without SDI	4,090	3,967	4,038	4,174	4,102	4,342	6
Total RDT&E	24,829	27,371	29,322	30,464	30,568	29,663	19

[a] This category does not include funding for the University Research Initiatives (URI) Program.

[b] This figure does not include the transfer of $250 million of OSD-managed projects to DARPA.

[c] According to DoD, although SDIO was allocated $49 million to begin its research activities, the three Services plus DARPA were already conducting about $1.2 billion in SDI-related research in fiscal year 1984 (in 1984$).

[d] Reflects $1,250 million of SDI-related work in fiscal year 1984.

SOURCE: Office of the Secretary of Defense.

Table 3—Individual Service Funding for Research (6.1) (in millions of dollars)

Year	Army	Navy	Air Force
1980	130.7	214.9	119.2
1981	144.4	241.4	126.6
1982	179.2	276.5	147.4
1983	206.2	307.6	166.4
1984	216.5	320.6	191.4
1985	231.5	341.2	201.3
1986	250.3	342.3	210.2
1987	219.5	354.3	223.3
1988	168.9	342.1	197.7
1989	172.7	355.3	196.4

SOURCE: Office of the Secretary of Defense.

gram by 12 percent and cancelled its ILIR program for fiscal year 1988. In fiscal year 1987, ILIR comprised about 7 percent of the Army's research budget, or $16 million, spread among its 31 laboratories on a competitive basis.

The ILIR programs serve a number of important purposes for Service laboratories. Because they are a principal main source of discretionary research funds, the Service ILIR programs help the labs maintain an atmosphere of creativity and research excellence, enhance their S&T base, provide seed money that can lead to new research efforts, and assist the laboratory directors in hiring new Ph.D.s.

In its 1987 summer study on technology base management the DSB stated that "a successful laboratory requires discretionary basic research funding for its long term vitality." The DSB went on to recommend that "at least 5 percent, and up to 10 percent, of the annual funding of Federal laboratories" should consist of ILIR funds.[17]

In meetings with OSD the Army reassured the DDDR&E(R&AT) that funding for the research program would be restored as soon as possible. However, in fiscal year 1988, the Army cuts its research program an additional 23 percent, and canceled the ILIR program. After several meetings with top Army RDT&E officials, the DDDR&E decided not to raise the 6.1 funding issue to the DDR&E level.

Promoting Cooperation Among the Services and DARPA

There is a long history of inter-Service rivalry and difficulty in cooperation between the Services and OSD. Further, cooperation between the Services and DARPA is hindered because DARPA reports to the DDR&E while the Service S&T representatives report to the DDDR&E(R&AT). Starting with the National Security Act of 1947, Congress has taken a number of steps to strengthen OSD as a centralizing and coordinating body. Many analysts believe that these efforts have generally been unsuccessful.[18] It is probably too early to tell if the recent Goldwater-Nichols Act will be successful in improving OSD centralization and coordination capacity.

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[17] U.S. Department of Defense, Office of the DDR&E, "Report of the Defense Science Board, 1987 Summer Study on Technology Base Management" (Springfield, VA: National Technical Information Service, December 1987), p. 15.

Inter-Service rivalry is not necessarily all bad. In his book *Bureaucracy and Representative Government*, William Niskanen states that "competition among bureaus promotes efficiency by reducing the cost of certain services." Niskanen points out that redundancy can guard against catastrophic failure of one or more programs.[19]

Certainly there are advantages in using competitive approaches. However, there are limits to the extent to which competition can contribute to the success of the DoD S&T program. In an environment where the rapid development and deployment of a technology often is important, excessive competition usually results in poor coordination, which slows the introduction of new S&T capabilities. Representatives from OSD and the Services have stated to OTA staff that inter-Service rivalry often has played a major role in delaying the development of important technologies (such as remotely piloted vehicles).

There have been instances in which OSD, the Services, and DARPA have been able to overcome some of these difficulties. One example is the recent establishment of the Balanced Technology Initiative (BTI). Established by Congress in fiscal year 1987, the BTI is intended to develop new technologies to "substantially advance our conventional defense capabilities." The National Defense Authorization Act for fiscal year 1987 indicated that BTI funds were to be used to "expand research on innovative concepts and methods of enhancing conventional defense capabilities," and to promote "restoration of the conventional defense technology base."[20] Responsibility for planning, development, and oversight of the BTI program was assigned to the DDR&E. The makeup of the BTI planning team, chaired by a representative from the office of the DDDR&E(R&AT), was unusual because it included the Services, DARPA, SDIO, and four other OSD organizations: Tactical Warfare Programs, Strategic and Theater Nuclear Forces, International Programs and Technology, and the Undersecretary of Defense for Policy. Funding for the program was appropriated by Congress to OSD to be divided among the Services, SDIO and DARPA.

Despite initial skepticism by the Services and DARPA, the BTI program appears to enjoy strong, although not universal, DoD and congressional support. One reason might be that OSD did not develop program guidelines on its own and then ask the Services and DARPA to forward proposals based on those guidelines. Rather, OSD made a deliberate decision to include all of the interested parties in the process of developing the BTI guidelines. All of the participants played a role in the development of its overall goals, and knew that project selection was tied to the ultimate goals of the program rather than just technological competence.[21] OSD officials tried to take advantage of European technological knowledge and capabilities during the initial planning stages. The BTI planning team was also successful in designing broad project implementation and evaluation procedures. Finally, the BTI report to Congress tied each of the programs to a crucial component of the air-land and maritime strategy, not to a program funding element; essentially, the BTI planning team tied each project to a component of the conventional warfare doctrine.

It is still too early to evaluate the success of the BTI. Like other congressionally mandated programs, the BTI was greeted with skepticism in the Services and OSD because congressional interest and funding support for such special initiatives often have been fleeting.[22] Nevertheless, rather than developing program guidelines and objectives independently, OSD appears to have tempered this skepticism by creating an environment in which all interested parties are willing to cooperate in the development and implementation of the BTI program.

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[18] Daniel J. Kaufman, "National Security: Organizing the Armed Forces," *Armed Forces & Society*, Mar. 16, 1988, p. 15.

[19] William Niskanen, *Bureaucracy and Representative Government* (Chicago, IL: Aldine, Atherton, 1971).

[20] Robert C. Duncan, DDR&E, *Department of Defense Statement on the Balanced Technology Initiative*, presented before the Committee on Armed Services, U. S. Senate, Apr. 11, 1988, p. 2.

[21] Guidelines for selection included the following: 1) Projects had to be consistent with the stated intent of Congress. 2) Emphasis had to be on technology areas that address recognized conventional force needs (e.g., chemical, biological defense, and nuclear programs were generally excluded). 3) Projects should offer both short- and long-term potential for enhancing conventional force needs. Preference would be given to ongoing work that offered a high payoff in military effectiveness, with limited additional funding. 4) SDIO suggestions should be presented as technological spinoff opportunities with relevance to conventional defense needs (e.g., hypervelocity guns and projectiles, high-power microwaves, and advanced seekers and sensors). 5) A certain number of projects had to involve joint programs, such as Services/DARPA, multi-Service, or international cooperation.

Evaluating the Goals of the Technology Base Programs

OSD and the Services have not developed a systematic, DoD-wide approach for determining the extent to which technology base programs actually satisfy goals set by OSD. OSD officials and Service representatives typically describe two goals of the S&T programs: maintaining technological superiority over the Soviet Union, and being a smart buyer of technology and technological expertise. Other technology base goals, such as reducing complexity and cost, improving productivity of the industrial base, sponsoring the highest-quality S&T work, and enhancing return on investment, receive comparatively little emphasis.

Moreover, although there is seemingly a general consensus on what it means to keep ahead of the Soviet Union, there appears to be much less agreement regarding what it means to be a "smart buyer." OSD and the Services appear to have no systematic way of determining whether they are smarter buyers of technology and weapon systems today than they were, say, 10 years ago. It appears that OSD and the Services take it "on faith" that a sustained effort in various S&T activities provides them with the ability to make intelligent investments in S&T and weapon systems development.

Evaluating Research Activities

When OTA asked OSD representatives how they spent their time, the responses focused on three things. First, most of the respondents said they spend too much time on the long process of reviewing and defending their programmatic budgets. Second, OSD personnel spend time responding to DoD internal requests. These requests include technical questions, providing information for the DoD Inspector General, responding to General Accounting Office audits, or trying to prevent one of the Services from shifting funds away from an S&T program. Third, the respondents indicated that they spend more and more of their time trying to satisfy congressional requests. According to a recent article, in 1970 Congress requested 31 reports or studies from OSD. By 1985 that number had climbed to 458. Concomitantly, legal provisions detailing how DoD is to carry out certain aspects of its responsibilities have increased from 64 to 213, while annual congressionally mandated actions requiring specific DoD compliance increased from 18 to 202.[23] OSD representatives gave the impression that they were drowning in a sea of internal and external accountability and bureaucratic red tape.

Many respondents indicated that they spent only a small portion of their time performing duties that require science and technology skills. It appears that too many OSD—as well as Service—R&D managers are required to spend an inordinate amount of time defending their budgets, responding to DoD bureaucratic red tape, or answering an ever-growing number of congressional inquiries, leaving little time to evaluate R&D activities.

ORGANIZATION OF OSD FOR OVERSIGHT

DoD's current organizational arrangement for managing S&T activities contributes to the difficulties OSD encounters in shaping a coherent technology base strategy, and to the problems described above.

As a result of the Goldwater-Nichols Act, DoD has reorganized the management of its RDT&E activities. The Act abolished the office of Under Secretary of Defense for Research and Engineering and replaced it with the USD(A). The legislation also re-created the Office of the DDR&E, which reports to the USD(A). (See figure 2.)

The USD(A) has oversight responsibility for all of DoD's technology base programs, except those of SDIO. That oversight responsibility is delegated to the DDR&E, who in turn delegates oversight of the Services' programs to the DDDRE(R&AT). The director of DARPA is supposed to work closely with the DDDR&E(R&AT), but reports directly to the DDR&E.

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[22] The Services are generally satisfied with the conventional programs the BTI is currently supporting. However, Congress did not provide any additional funding for the BTI in fiscal year 1990. Consequently, OSD will fund the BTI program by taxing other conventional technology base efforts of the Services. The Services argue that OSD's action in this instance has greatly compromised the original intent of the BTI program.

[23] Kaufman, op. cit., footnote 18, p. 5.

The current DoD RDT&E organizational structure raises a number of concerns. The first centers on the primary responsibilities of the USD(A). The Packard Commission stated that it was crucial for the new USD(A) to have full-time responsibility for managing the defense acquisition system, setting R&D policy, and supervising the performance of the entire process including procurement, logistics, and testing. The Under Secretary is also responsible for developing contract audit policy, supervising the oversight of defense contractors, and preparing annual reports to Congress on major issues of acquisition policy and program implementation. With the procurement budget many times larger than the tech base budget, members of the defense R&D community are afraid that their concerns will take a back seat to the USD(A)'s broad menu of acquisition responsibilities.

Some OSD and Service representatives believe that it is too early to tell whether the technology base programs will suffer as a result of the reorganization. However, other DoD officials contend that S&T programs have already experienced some setbacks. They note, for example, that the USD(A) recently removed the office responsible for international R&D cooperative programs from the DDR&E's office. The newly created Deputy Under Secretary of Defense for International Programs and Technology is still responsible for cooperative foreign R&D programs but now reports directly to the USD(A). However, according to the 1986 Nunn Amendment, by 1994, 10 percent of the RDT&E programs are to have foreign involvement. Representatives of the office of the DDR&E believe that they should have oversight responsibilities for those programs. Currently there are about 20 foreign S&T cooperative projects.

A second organizational problem concerns the reestablishment of the DDR&E. The DDR&E was originally established as part of the 1958 Department of Defense reorganization Act. The DDR&E was given greater responsibilities in 1977, and elevated to the Under Secretary of Defense for Research and Engineering [USD(R&E)] as part of Secretary of Defense Harold Brown's management reforms.

Some DoD officials contend that the reestablishment of the DDR&E as subordinate to the USD(A) might be interpreted as a lowering of status for R&D, since the DDR&E no longer has direct access to the Secretary of Defense. Various OSD representatives have argued that if science and technology are the cornerstone of the military's defense capabilities, then S&T programs should have direct access to the Secretary's office. They fear that, without such direct access, important S&T issues such as cooperative foreign R&D programs will get lost in the acquisition shuffle. Others, however, assert that only technology that gets fielded in military systems has any value for defense, and that the DDR&E is appropriately placed under the USD(A). They claim that the reestablishment of the DDR&E will not present a problem if the USD(A) strongly supports the S&T programs.

Managing Technology Base Activities at DARPA and SDIO

The Role of DARPA

A third concern is the role that DARPA and SDIO play in supporting DoD's technology base programs. DARPA was established in 1958, partly as a result of the launching of the initial Sputnik satellites. The President and Congress also recognized that DoD needed an organization that could "take the long view" regarding the development of high-risk technology. DARPA was thus set up to be DoD's "corporate" research organization, reporting to the highest level, and capable of working at the cutting edge of technology. DARPA's organization allows it to explore innovative applications of new technologies where the risk and potential payoff are both high, and where success might provide new military options or applications—or revise traditional roles and missions. In theory, since DARPA has no operational military missions, it should be able to maintain objectivity in pursuit of research ideas that hold promise for important technology advancement for all of the Services.

DARPA executes its programs mainly through contracts with industry, universities, nonprofit organizations, and Government laboratories. DARPA now has a limited in-house contracting capability, but most of its contracts are still managed by the Services.

Although DARPA was originally established as a small agency to promote the rapid diffusion of new and creative ideas, in the past two years DARPA's budget has ballooned to over $1 billion, sponsoring almost 25 percent of the military's S&T work.[24] Further, in 1986 DoD announced that DARPA's role as a developer of technology would include prototyping.

The recent rapid growth in DARPA's budget and its additional prototyping responsibilities have raised several concerns within the defense community. First, OSD and Service representatives have had problems coordinating technology base activities with DARPA. They contend that part of the problem is DARPA's independence and its separate reporting chain within OSD. All three Services have complained that DARPA seldom involves them in its initial planning activities for joint DARPA/Service projects. The Services note that DARPA often chooses not to participate in important technology base activities. Many experts believe that efforts to improve DoD-wide technology base planning and coordination would require full participation by DARPA.

A second concern revolves around the changing nature of DARPA's technology base activities. Of the $1,270 million DARPA budget for fiscal year 1989, only $88 million is for basic research. There is growing concern, inside and outside DoD, that DARPA may be supporting too much applied research and technology demonstration activities rather than longer-term, high-risk basic research. In testimony before the House Science and Technology Committee's Task Force on Science Policy, Norman R. Augustine, a member of the DSB and then the executive vice president of Martin Marietta corporation, stated that:

> In decades past, the effort of the [Defense] Advanced Research Projects Agency was focused upon advancing basic research and applied research. Over the years since its inception, however, the funds allowed to DARPA have been, to an increasing degree, used for prototype demonstrations—a very worthwhile undertaking in its own right but nevertheless still a major drain on the basic research resources originally intended at the time DARPA was established.[25]

The changing nature of DARPA's technology base work leads to a third organizational issue: DARPA's alleged past difficulties in transferring technology to the Services. DARPA is not the only organization, public or private, to struggle with technology transfer problems, and over its 30-year history DARPA has had a very impressive record of successfully transferring such technologies as stealth, directed energy, and some types of lasers to the Services. Nevertheless, many OSD and Service representatives strongly criticized DARPA's current technology transfer activities, particularly with regard to prototyping and technology demonstration programs. This has taken on particular importance in recent years, as Congress has turned to DARPA to address Service-related advanced technological problems in such areas as anti-submarine warfare, anti-armor applications, and lighter-than-air technology.

Two recent studies seem to reinforce the OSD and Service technology transfer concerns. In 1985, at DARPA's request, both the National Security Industrial Association (NSIA) and the Technology Transfer Center at George Mason University conducted studies of the particular technology transfer process associated with DARPA's large technology demonstration programs. Both of these studies concluded that DARPA's technology transfer activities rely too much on individual initiatives, resulting in a very weak and haphazard approach to the technology transfer process. The NSIA study noted that "DARPA is often too insensitive or unaware regarding the needs and problems of the Services." The NSIA panel indicated that an "increase in the awareness and sensitivity to the Services needs need not compromise DARPA's essential free thinking."[26]

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[24] OSD estimates that for fiscal year 1989 DARPA's budget will be about $1,270 million. Of that amount, $250 million will consist of work transferred out of OSD to DARPA. These projects include the SEMATECH initiative, the Monolithic Microwave Integrated Circuit (MMIC) program, the Software Technology for Adaptable Reliable Systems (STARS), and several other programs. The OSD projects will be primarily managed by OSD personnel who have been transferred to DARPA from the disbanded Computer and Electronics Technology Directorate in OSD. The remaining $1,000 million (approximately) consists of about $700 million requested by DARPA and a total of about $300 million added on by Congress.

[25] Norman R. Augustine, Martin Marietta Corp., testimony at hearings before the House Committee on Science and Technology, Task Force on Science Policy, Oct. 23, 1985, pp. 3-4.

Both studies recommended that DARPA develop a written Agency-wide technology transfer plan for all technology demonstration activities. Among other things, this plan should ***require*** all program managers to work closely with the appropriate Service when undertaking a technology demonstration project. Both studies recommended that DARPA make available to all Program Managers a central historical database of successful and unsuccessful technology transfer strategies based on actual program experience. The studies pointed out that given the short tenure of DARPA professional staff (about 3 to 4 years), a written plan and central database would help improve the long-term continuity of DARPA's technology demonstration programs.

Despite these strong recommendations, DARPA has not yet developed a formal technology transfer plan. OSD and the Service representatives assert that if DARPA continues to pursue its technology transfer activities as it has in the past, many good technological opportunities could be wasted. However, this problem is not unique to DARPA; OTA has not found any formalized written technology transfer procedures developed by OSD and the Services.

The Role of SDIO

The Strategic Defense Initiative Organization (SDIO) was established as a separate agency of the Department of Defense in 1984, with the director reporting to the Secretary of Defense. The SDIO's mission is to "provide the technological basis for an informed decision regarding feasibility of eliminating the threat posed by ballistic missiles and increasing the contribution of defensive systems to U.S. and allied security."[27]

As indicated in table 3, the SDIO budget has grown rapidly over the past 5 years. Although the entire SDIO budget is contained within the 6.3A budget category, not all SDI activities are advanced technology demonstration efforts. For example, SDIO's Innovative Science and Technology Office (ISTO) has the mission of establishing the feasibility of revolutionary concepts with the potential for application to specific SDI technological needs. Like DARPA, the ISTO executes its research contracts through the Services. The ISTO estimates that in fiscal year 1988 and fiscal year 1989 it will support $100 million in SDI-related research.

SDIO also supports exploratory development (otherwise funded under category 6.2). Because there is no separate office that manages such work, it is very difficult to determine how much exploratory development SDIO is currently funding. OTA asked SDIO if it could determine the dollar amount of research and exploratory development projects it supports on an annual basis. According to the SDIO comptroller, SDIO does not fund any true research activities.[28] SDIO's research efforts do not match DoD's accepted definition of research. However, the director of ISTO indicated that 80 percent of the projects his office supports do qualify as research. OSD and Service representatives agree that ISTO sponsors short-term research programs, with heavy emphasis on solving specific SDIO challenges.

The comptroller maintains that all of ISTO's efforts really fall under the definition of exploratory development. The report concludes that approximately 20 percent of the SDIO budget is devoted to exploratory development work.

SDIO is funding about $700 million of exploratory development work with no formal coordinating ties to the three Services and DARPA. Presently, the only coordinating activities occur informally, as the individual Services and DARPA manage SDIO's exploratory development contracts. OSD and Service representatives have stated that SDIO should participate in OSD's technology base investment strategy activities. Taken together, the current organizational arrangement and the mission of the SDIO program make such participation unlikely. According to the Air Force, however, SDIO projects conducted in Air Force laboratories differ from DARPA projects because they are well integrated into the laboratory program. Such coordination and integration usually occurs at the laboratory (or lab division) level.

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[26] National Security Industrial Association, "DARPA's Technology Transfer Policy," December 1985, p. 7.

[27] Gerald Yonas, Acting Deputy Director and Chief Scientist of SDIO, "The Strategic Defense Initiative Science in the Mission Agencies & Federal Laboratories," testimony at hearings before the House Committee on Science and Technology, Science Policy Task Force, Oct. 23, 1985, p. 543.

[28] The comptroller of SDIO provided OTA with a written estimate of how much technology base work SDIO is currently supporting, by category.

Recruiting and Retaining Scientific Personnel

According to OSD and Service representatives, DoD is often unable to recruit the very best scientific, technical, and managerial talent. Because of growing salary disparities between the government and the private sector, OSD is losing many top level S&T managers.

The late Philip Handler, former president of the National Academy of Sciences, once pointed out that in science the best is vastly more important than the next best. Both the 1983 Packard Report and the 1987 DSB report concluded that OSD and the Services face serious disadvantages in hiring and retaining top S&T personnel for three primary reasons: inadequate civil service compensation, "revolving door" restrictions, and a lowering of status associated with Federal employment.

A recent unpublished Navy study found that since the early 1980s, the disparity between Federal salaries and salaries in industry and academia has greatly expanded. For example, the average compensation for S&T managers in the upper 10 percent of the private sector was $40,000 to $50,000 higher than for their Government counterparts. Another internal Navy survey of university principle investigators (PIs) found that, for the first time, the majority of PIs' salaries were higher than government salaries. Some 60 percent of university PIs are paid salaries that exceed the Federal pay cap, with approximately one-third of them exceeding $90,000.

This problem is likely to become more pressing in the future. Changing demographics will produce a work force with greater ethnic diversity and more women. Minorities and women have not contributed in substantial numbers to science and engineering in the past. The challenge will be to expand the participation of women and minorities in science and engineering college programs and graduate schools and, ultimately, to offer them rewarding careers working in defense technology base and related program areas.[29]

Salary disparity has also contributed to a high level of turnover among top-level OSD political appointees. For example, between 1981 and 1988 there were three different USD(R&E) officials, and five individuals have held the position that is now DDDR&E(R&AT). An internal OSD study indicated that the overall quality of its S&T political appointees was very inconsistent.

Pre-employment and post-employment personnel restrictions also mitigate against recruiting first-rate political appointees. Such officials are required to divest themselves of any financial interest in any company conducting business with DoD. This requirement can result in serious tax consequences for the political appointee. Further, many prospective employees resent the prospect of filing an annual financial disclosure statement.

The main postemployment restriction concerns the recently amended "revolving door" legislation. The revised law restricts the kinds of services former military officers and DoD employees may perform for a future employer that does business with the Defense Department. Among other things, this law imposes a "2-year ban on certain former Department of Defense personnel receiving compensation of more than $250 from defense contractors (who have contracts in excess of $10 million with the government) if the former officers or employees had official procurement duties relating to that contractor during the 2-year period prior to separation from government service."[30]

According to OSD and Service representatives, the revolving door legislation has significantly limited DoD's ability to hire top-level S&T managers from the private sector who have had experience working in the defense arena. Compared with their predecessors, many top-level S&T managers now come to DoD with little or no defense experience. This situation has contributed to the increasing period of time it takes new DoD S&T managers to understand the complexities of the overall defense environment.

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[29] U.S. Congress, Office of Technology Assessment, *Educating Scientists and Engineers: Grade School to Grad School* (Washington, DC: U.S. Government Printing Office, June 1988); and U.S. Congress, Office of Technology Assessment, *Higher Education for Scientists and Engineers—Background Paper*, OTA-BP-SET-52 (Washington, DC: U.S. Government Printing Office, March 1989).

[30] Jack Maskell, Library of Congress, Congressional Research Service, "Post Employment 'Revolving Door' Restrictions on Department of Defense Personnel," July 5, 1988, p. 3.

DoD SUPPORT OF ITS TECHNOLOGY BASE PROGRAMS

In 1953, President Eisenhower said that, despite the establishment of the National Science Foundation, Federal agencies such as DoD would have to continue performing and supporting basic research closely related to their missions. Since then DoD officials have asserted that basic research provides information on natural phenomena that DoD could use in the development of modern weapons.

In 1963 Harold Brown, then DDR&E and subsequently Secretary of Defense, said that "as the largest user of scientific and technical information in the Federal Government, DoD had an obligation to replenish this information." Brown went on to say that DoD has to support a broad range of research that may or may not be directly related to its mission.[31] DoD representatives contend that in an era of rapid technological change and growing Soviet S&T competence, DoD support for a strong and diverse technology base program is imperative.

Despite these strong statements of support, funding for DoD's S&T programs has been inconsistent over the past 20 years. As table 4 indicates, beginning in 1970, funding for research (in constant dollars) began to decline and did not exceed its 1970 level of support until 1986. Moreover, since the peak year of 1986, funding for research has declined more than 4 percent in constant dollars.

Similarly, support for exploratory development declined until the late 1970s. Then it rebounded, nearly returning to its 1970 level by 1983—in constant dollars. Between 1984 and 1989, however, support for exploratory development again fell by almost 10 percent.

By almost any measure—total constant dollars, fraction of DoD budget, fraction of RDT&E budget—the level of DoD support for its research and exploratory development programs has decreased over the past 20 years. In the mid-1960s, research and exploratory development represented 25 percent of the total RDT&E budget. By 1989 it had shrunk to less than 9 percent. Between 1970 and 1988, 6.1 and 6.2 funding declined as a percent of DoD's total obligational authority (TOA), from 1.79 percent to 1.27 percent. Further, as table 4 shows, since 1983 DoD has moved its resources from research and exploratory development programs to advanced technology development (ATD) programs.

Between 1984 and 1989, constant dollar funding for 6.1 and 6.2 programs declined 3 percent and 6 percent, respectively (see table 2). During the same period, funding for advanced technology development (ATD) exclusive of SDI increased 12 percent, while support for the SDI program rose 157 percent.[32]

The recent rapid growth of both ATD and SDI programs has taken its toll on the basic research and exploratory development programs. OSD and Service representatives have indicated that DoD is putting greater emphasis on ATD activities to improve the transfer of new technology to weapon systems. For example, in 1984 DoD reduced funding for its exploratory development program by $300 million while increasing ATD by $500 million. According to OSD personnel, the switch in funding was nothing more than an accounting change: a review of the programs supported under exploratory development revealed that a good portion of the work should have been classified as ATD.

In testimony before the House Armed Services Committee, the DDR&E, Dr. Robert Duncan, said that the growth in the ATD program and the SDI program has offset the losses in research and exploratory development. However various OSD and Service representatives contest this statement, insisting that those technology base activities which SDI currently supports are aimed exclusively at solving SDI-related problems. Consequently, potential benefits flowing from SDI into technology base programs will be long term, and probably more

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[31] Ralph Sanders (ed.), "Research: Meaning of the Term," in *Defense Research and Development* (Washington, DC: Industrial College of the Armed Forces, 1968), p. 73.

[32] This calculation is based on DoD information that the three Services and DARPA were supporting about $1.2 billion in SDI-related research in 1984.

Table 4—DoD Technology Base Funding Trends (millions of 1982$)

Year	Research (6.1)	Exploratory Development (6.2)	Advanced Technology Development[a] (6.3A)	SDIO[b]	Total without SDI	Total with SDI
1970	779	2,418	—	—	3,197	—
1971	728	2,238	—	—	2,966	—
1972	712	2,414	—	—	3,126	—
1973	629	2,306	—	—	2,935	—
1974	579	2,126	567	—	3,273	—
1975	530	1,923	631	—	3,084	—
1976	528	1,902	677	—	3,107	—
1977	556	1,947	734	—	3,237	—
1978	576	1,937	697	—	3,210	—
1979	608	1,972	725	—	3,306	—
1980	653	2,021	676	—	3,350	—
1981	660	2,134	600	—	3,393	—
1982	697	2,233	738	—	3,668	—
1983	754	2,357	792	—	3,903	—
1984	778	2,051	1,261	1,109	4,090	5,199
1985	760	2,032	1,175	1,243	3,967	5,210
1986	831	1,984	1,223	2,318	4,038	6,356
1987	756	1,985	1,433	3,156	4,174	7,330
1988	740	1,924	1,438	2,957	4,102	7,059
1989	755	1,928	1,658	2,849	4,342	7,191

[a] The 6.3A category was established in 1974.
[b] Established in 1984.

SOURCE: Office of the Secretary of Defense.

expensive than if they had been supported directly through S&T activities.

The IDA task force stated the consequences bluntly:

> If the decline in resources devoted to science and technology is not reversed, the impact on the related technological capabilities of U.S. weaponry and forces may be compromised so much that we will need to rethink our basic strategy of using qualitatively superior weapons to offset numerical disadvantages.[33]

While DoD's RDT&E program has experienced significant growth in the 1980s (see figure 3) the S&T portion of the budget has not shared in that expansion. Between 1980 and 1989 the RDT&E budget increased 90 percent in constant dollars, while the S&T programs (excluding SDI) increased only 16 percent.

According to OSD and Service representatives, two primary reasons explain this relatively small increase. First, technology base programs do not enjoy strong support at the highest levels within the military. Similar findings were reported by the IDA task force, and the DSB in its 1987 summer study of DoD S&T programs. In its report the DSB stated:

> Where once OSD exerted a centralized point of unified leadership and budgetary authority and control for the 6.1 program, the Study Group is concerned that this leadership is fragmented by delegation to the Services and agencies; the 6.1 program has, in effect, been relegated to a position of second or third order of importance and lacks top management attention. Stated bluntly, DoD "corporate management" has essentially abrogated some of its responsibility for long range vitality and competitiveness.[34]

OSD and Service representatives believe that military leaders do not appreciate the role that past S&T accomplishments have played in providing technologically superior weapons. Top Pentagon leaders are often willing to sacrifice 6.1 and 6.2

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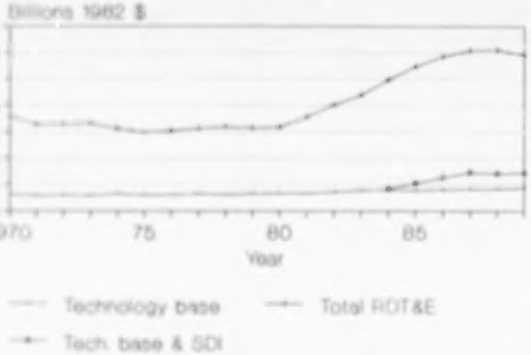
[33] Institute for Defense Analyses, op. cit., footnote 6, p. 4.

[34] U.S. Department of Defense, op. cit., footnote 17, p. 13.

Figure 3—Comparison of RDT&E and Technology Base



SOURCE: Data provided by the Office of the Secretary of Defense.

activities in order to protect budgets for immediate and visible needs, such as tanks and planes. The consequences of reducing the force structure, terminating weapon systems, or delaying procurement are much more visible than a particular research program which may not bear fruit for 10 to 15 years, if ever. Unfortunately, this attitude has not served the technology base programs well in times of tight budgets. It has resulted in military leaders "raiding" S&T programs to help pay for downstream system development programs. As was noted earlier, the recent growth in the ATD budget to improve DoD's near-term technology transfer concerns has come at the expense of the research and exploratory development.

Focusing on near-term defense needs in resolving budgetary conflicts tends to bias the subject matter of DoD research. There is considerable agreement within OSD and the Services that much of DoD's research program is aimed at meeting the short-term needs of the military, and that it is easier to obtain top-level support for research activities that can be related to specific military needs. This is a point of contention. Many of those actively involved in the S&T programs believe that this is a misuse of research funds. They contend that it is unwise to direct the research program toward the solution of near term problems because military utility can come from all areas of science and engineering. By this logic, it is in DoD's best interest to be involved in a wide range of research problems, to follow their progress carefully, and to apply long term scientific reserch to present and future needs.[35]

A recent internal OSD evaluation of DoD's research programs concluded that many of its research projects in such fields as mathematics, chemistry, computer sciences, and physics were "too well connected to current military needs." The OSD review instructed Service 6.1 managers that "you should be reaping the fruits of seeds sown by your predecessors, and you should be sowing the seeds which will bear fruit for your successors several times removed."

This very same concern was discussed in the DSB's 1987 summer study on the technology base. The DSB report concluded, "The need for short-term results and immediate 'relevancy' has become the governing criterion in framing a program. We have experienced a 'research menu squeeze' in which the most popular programs, justifiable in terms of clearly perceived near-term military relevancy, survive the cut."[36] The DSB report urged the Services to pursue more research activities with longer term objectives. On the other hand, some argue that basic research is funded within DoD precisely because the Defense Department can give it a focus that makes it relevant to military needs.

CONCLUSION

There is a serious question as to whether OSD is currently fulfilling its technology base oversight responsibilities in a satisfactory way. There is general agreement, inside and outside of the Pentagon, that OSD has not developed an overall technology base investment strategy. Many within the Services contend that, for a number of reasons, OSD should not attempt to develop a coordinated technology base investment strategy, and that the current decentralized system is probably better. But others assert that such a large technology base program, with important national security implications, ought to possess some overall central leadership and guidance.

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[35] George Gamota, "How Much Does the Defense Department Advance Science?" in proceedings of an American Association for the Advancement of Science (AAAS) symposium, Naval Research Center, Washington, DC, Jan. 8, 1980 (published Sept. 24, 1980), p. 4.

[36] U.S. Department of Defense, op. cit., footnote 17, p. 12.

Implementing an OSD-guided investment strategy would not be a panacea for all the challenges confronting DoD's technology base programs. A coordinated investment strategy could: 1) help create a process for making OSD-directed strategic decisions, 2) allow OSD and the different agencies to focus on the outputs of the S&T programs and not just the inputs, and 3) enhance the understanding of DoD technology base programs.

A coherent technology base investment strategy would assist Congress in its review of defense S&T programs. In the absence of a clearly articulated technology base strategy, Congress is forced to focus its review on numerous individual program elements. A technology base strategy that included a rational list of priorities would enable Congress to take a broader view of the Pentagon's S&T programs. Congress might then focus its attention on the extent to which DoD's proposed technology base program satisfies its overall strategy and stated priorities.

Despite the Goldwater-Nichols Act, OSD's current organizational arrangement presents problems for coordinating the different technology base programs. Without the full participation of DARPA and SDIO, a coherent technology base program will be very difficult to achieve.

Clearly there is no magic formula for DoD to use in determining the "right" level of support for its technology base programs. After numerous discussions with individuals outside and inside the defense community, OTA has identified several criteria that might usefully be applied to evaluating the overall strength of DoD's science and technology programs.

First, it is essential for an organization to maintain strong support for a broadly based science and technology program. Top corporate managers, responsible for maintaining the overall health of their science and technology programs, must have a deep understanding of how a strong technology base program can help an organization attain both its short and long term S&T goals. DoD's technology base programs do not enjoy consistent high-level support within OSD and the Services. An organization's research program should be strong and diverse enough to attack any problem related to the organization's mission. As the director of research for a large industrial corporation told OTA, he wants his S&T people to be "swimming in a sea" of company-related research problems.

Second, individuals responsible for managing S&T programs need a clear mission statement that guides the overall makeup of the S&T programs. The mission should be developed by a critical number of people throughout the organization and understood by all. DoD asserts that the primary mission of its S&T programs is to offset the numerical advantages and growing technological sophistication of Soviet forces. But recent studies criticize DoD for focusing too strongly on the Soviet Union, arguing that the military must be prepared to engage in a number of different combat arenas.[37] There is little agreement within OSD and the Services on how the technology base programs should be structured to meet the diverse security challenges that will confront DoD in the future.

Third, a strong S&T organization must be able to recruit, hire, and invest in the very best S&T talent. These new people should be exposed to a strong orientation program that helps them understand how their work will contribute to attaining the overall S&T mission. In order to conduct a vital S&T program, DoD must achieve the ability to recruit and retain top flight scientists and engineers.

Fourth, many researchers, both inside and outside the Pentagon, contend that DoD needs to maintain greater funding stability for its technology base programs. This is especially true for the early stages of research activities.[38] DoD's research and exploratory development programs have suffered since the establishment of SDI. Over the last six fiscal years (1984-89), DoD has been the only major Federal R&D sponsor to experience a funding decline, in constant dollars, for basic research. A continuation of these trends could jeopardize a pillar of U.S. defense strategy.

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[37] See, for example, Fred C. Ikle and Albert Wohlstetter, "Discriminate Deterrence," Report of The Commission On Integrated Long-Term Strategy, Jan. 11, 1988.

[38] U.S. Department of Defense, op. cit., footnote 17, p. 11.

The director of research at a Department of Energy (DOE) laboratory speaks of "recovery research." When an organization fails to support a broadly based research program, it often experiences difficulty with new products as they move into development. Consequently, in order to correct such problems, the organization is forced to engage in recovery research, which is costly and time-consuming. The DOE official stated that the more an organization has to perform recovery research, the greater the probability that its S&T programs are not receiving enough support. An OSD official told OTA that he believes that DoD has to support too much recovery research.

Finally, a strong S&T program must be closely coupled to the developers and ultimate users of technology. This is an important avenue of communication for managers to ensure that their S&T programs are solving the right problems. Some Service officials complain that technology base people are not always consulted when new weapon specifications are developed. For example, Army S&T representatives told OTA that they were not consulted when the Light Helicopter Experimental program specified an automatic target recognition capability (ATR). According to these officials, they knew that an ATR capability was (and still is) not feasible. The Army now refers to this concept as aided automatic targeting recognition (AATR).

Chapter 5

The Management of Defense Department Laboratories

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Chapter 5

The Management of Defense Department Laboratories

INTRODUCTION

Three problems—personnel, funding, and size—hinder virtually all of the laboratories operated by Department of Defense (DoD) employees in performing inherently governmental functions, acting as smart buyers, and incubating new concepts. The government's personnel system is too rigid because it makes it difficult for laboratories to compete with the private sector for professional staff, because pay scales are inflexible, and because of the obstacles it sets to rewarding performance. The laboratories find it difficult to get funds as and when they need them: They must spend their funds within the 12-month budgetary cycle, and they have limited authority to move money between acccunts, approve start-ups, and target discretionary money to building their technology base. Finally, most labs often cannot deploy a critical mass of scientists and engineers into new areas that may be vital to the lab's mission.

Alternative models to the government-owned, government-operated laboratory exist, for example the facilities operated under contract to the Department of Energy (DOE). Such models have certain common features. They operate under the contractor's own management systems. Their personnel systems enable them to compete on almost equal terms with universities and industry for scientists and engineers. Their funds are often available until spent. And they have the size and depth of expertise to work in the various disciplines needed for technology development.

The question that DoD and its technical managers confront is whether to continue the current system or to restructure the laboratories. As grave as the labs' problems are, conversion to government-owned, contractor-operated facilities (GOCO) may not be the answer. A conversion to GOCO could improve the laboratory's operations in the short term, while leaving its basic problems unchanged. No institutional approach can be divorced from the ends the institution is supposed to serve. The military Services must first decide what purposes their laboratories serve before taking the next step of altering long-standing institutional arrangements.

This chapter describes, compares, and contrasts the basic management arrangements of DoD's government-owned and -operated laboratories with those of comparable facilities, whether government-owned and contractor-operated or federally funded research and development centers (FFRDCs). It also raises a fundamental question: Why does the government in general, and the DoD in particular, need to develop technology through its own laboratories?

The problems of DoD's in-house laboratories are well documented. The next, and more difficult, task is to take the argument a step further: to consider some alternative approaches to technology development. The Defense Science Board (DSB) did this in its 1987 summer study, recommending that under carefully specified conditions *some* labs consider converting to a GOCO mode.[1] But the costs and benefits must be carefully weighed. After all, a GOCO military lab would still be dealing with the same sponsor whose rigidity prompted the conversion in the first place. Additionally, no government-funded institution can escape oversight merely by converting to contract. The reason is simple: Whether government-operated or GOCO, operating funds ultimately derive from congressional appropriations, and Congress holds the senior officials of the sponsoring agencies accountable for their proper use.

Beginning with a look at the roles of in-house military laboratories, this chapter explores the systemic problems they face in getting work done—problems of personnel management and development, starting and completing work, relations with the sponsoring agency, and the like. The discussion then turns to an alternative model, the multiprogram laboratories operated under contract to the DOE. The DOE national laboratories merit close study, first, because the relations between what is now DOE and its contractors have endured over four decades; second, because these labs seem to have the "critical mass" needed to bring very large technology development programs to fruition; and third, because the labs and their sponsoring agency have used the concept of "work for others" to redeploy professional staff as projects wind down, and to move into areas contiguous to their principal missions.

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[1] Defense Science Board, "Report of the Defense Science Board 1987 Summer Study on Technology Base Management," Washington, DC, December 1987.

After outlining both approaches to technology development, this chapter assesses both kinds of institutions with respect to five topics: 1) management flexibility, 2) the extent to which GOCO institutions tend to become more like government labs over time, 3) the ability of both kinds of institutions to transfer the results of their 6.1-6.3 programs to user organizations, 4) their mechanisms for diversifying within their basic missions, and 5) the ability of government labs to assimilate the more successful features of GOCO institutions.

GOVERNMENT-OWNED, GOVERNMENT-OPERATED LABORATORIES

Justifications for In-house Work

Government-owned and operated facilities can be justified for many reasons. First, apart from the issue of whether such labs serve as smart buyers, perform inherently governmental functions, or provide technical assistance for fielded systems, the relation of laboratory to sponsor is more clear cut than it is for other arrangements. Government operation avoids the criticism sometimes made of GOCOs that the government does not know whether a lab's executives identify with the government or the contractor who pays their salaries. As one authority notes, "in-house laboratories can be expected to share the sense of mission of their agency and to be responsive to their needs." Such labs provide stability and continuity "by simply continuing arrangements that have evolved historically."[2]

But such justifications skirt the important question: Why should technology for weapons systems, space exploration, or measurement protocols be developed out of government-staffed labs at all?

There are five principal justifications for such facilities:

- that certain functions are inherently governmental and may not be delegated to others,
- that the lab serves as a smart buyer, evaluating its contractors and keeping them at arm's length,
- that, through basic research, the lab can originate new concepts that, with support from its sponsors, may develop into fielded systems;
- that the lab can do special-purpose work for military customers that either is of no interest to industry or is kept from industry for security reasons, and
- that the lab can provide support to users once a weapons system has been successfully fielded.

Moreover, in-house laboratories can react quickly to military emergencies, as the Naval Research Laboratory's (NRL's) recent support for the fleet in the Persian Gulf shows.

Inherently Governmental Functions

The concept of "inherently governmental" functions is perhaps the fundamental justification for technology development institutions run by civil servants. As Budget Director David Bell told Congress in 1962, there are certain functions that may not be contracted out, functions that include:

> the decisions on what work is to be done, what objectives are to be set for the work, what time period and what costs are to be associated with the work . . . the evaluation and responsibilities for knowing whether the work has gone as it was supposed to go, and if it has not, what went wrong, and how it can be corrected on subsequent occasions.[3]

This position has important implications for the conduct of research at military laboratories. In this view, a laboratory or research and development center should have the capability to conceive of weapons development projects, develop technical specifications for industrial contractors, and supervise contractor efforts to ensure the reliability of systems and components in the early stages of development, regardless of cost.[4] Carried to its logical conclusion, this view holds that government scientists and engineers are a national asset that, within broad limits, should be retained beyond the immediate programs for which they were hired; that the lab is a going concern, not a job shop; and that its professional staff must do basic and exploratory research, simply to evaluate work done outside its walls.

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[2] T.J. Wilbanks, "Domestic Models for National Laboratory Utilization," in Energy Research Advisory Board, *Final Report of the Multiprogram Laboratory Panel, Vol. II: Support Studies* (Oak Ridge, TN: Oak Ridge National Laboratory, September 1982), p. 63.

[3] David Bell, Bureau of the Budget, *Systems Development and Management*, testimony at hearings before the House Committee on Government Operations, Military Operations Subcommittee, June 21, 1962, 87th Congress, 2nd Session, p. 44.

This basic philosophy is perfectly compatible with a number of arrangements. Government laboratories exist in every phase of dependence on their prime sponsor. A lab may: work exclusively for one sponsor or for several; perform reimbursable work for other organizations, as many service labs are doing for the Strategic Defense Initiative Organization (SDIO); serve as a corporate laboratory over and above its responsibilities to its parent agency; or (what often comes to the same thing) do work that is only loosely coupled to its sponsor's missions. There are even cases, like the optical facility at the Air Force Weapons Laboratory (Kirtland Air Force Base, New Mexico), of small GOCO units embedded in a government-run engineering center. Further, many military and civilian labs, particularly at the National Aeronautics and Space Administration (NASA), have chosen to contract out virtually all of their support functions—functions ranging from carting trash to managing the cafeteria to programming and operating tracking stations—without compromising their principal functions.

Smart Buyer

The laboratory may also function as a smart buyer, a role that complements its mission to plan development projects. The lab acts as smart buyer when it develops a particular technology—say, a new kind of integrated circuit, wideband recording device, or fault-tolerant avionics—that it can hand over to a contractor for further development and production, or when it evaluates private sector developments. In effect, the lab's R&D work presupposes, and depends on, the existence of a strong private sector R&D infrastructure. At this level, the justification for research is that a lab cannot assess technology without being thoroughly knowledgeable. As one DoD engineer put it, with some exaggeration, "if we go to a symposium and see something new, we're not doing our jobs."

In another sense, the in-house lab serves as a smart buyer when it proves a concept that may lead to new technology. The job of an engineering center working on, for example, very-high-speed-integrated circuit (VHSIC) technology is not to make the systems work, but to show that they *will* work. Actual operational success is in the hands of the buying commands, systems developers, and production people. A military service will insert VHSIC or other technologies only where the technology can "buy its way" into a weapons system.

Where a lab really acts as smart buyer is in bringing its expertise to bear in deciding when work in a certain area has gone as far as it should. As one technical director put it, his job "is to kill off projects that will not fly before costs get out of hand."

Long-term Research

The laboratory also serves as an incubator of new concepts. In fact, it is this role that serves as the principal justification for much 6.1 and 6.2 work carried out by DoD institutions. It is more obvious at NRL than at the other Navy R&D Centers—but nowhere is it insignificant. If NRL has become a corporate lab for all of DoD, it is because of its work in technologies that had no immediate application but that would ultimately define the technology for a new generation of weapons systems. NRL's work in a variety of fields—designing x-ray astronomy experiments, developing a unique class of electroactive polymers, perfecting ceramic-air composites for underwater sensors—positions the Navy to move into the development phase, confident that the technology to make systems work is available.

The importance of such advanced work may be gauged by the efforts of lab technical directors to increase their pot of 6.1 and discretionary funds—though it should be noted that the two are by no means the same. Most of them would agree, in the words of one of them, that the government "should support some tech base work that is independent of any particular program, because otherwise you may shut out some technologies that could become very important."

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[4] On this point, see Federal Coordinating Council for Science, Engineering and Technology, "A Research and Development Management Approach: Report of the Committee on Application of OMB Circular A-76 to R&D," Washington, DC, Oct. 31, 1979, pp. VI-VII.

The sponsoring of basic research at military laboratories serves a number of ends. Basic research can be justified as a means of enhancing the lab's reputation; indeed, most facilities try to hire the best science and engineering graduates by holding out the possibility of their doing some basic research. Such research makes scientists available to engineers to work on serious technical problems, without going into development work full time. Finally, basic research allows an engineering-oriented facility to develop a few special applications to military technology.

Yet the laboratory executives are caught on the horns of a dilemma. To try to justify basic research on the ground that it will lead to some definite payoff is self-defeating, especially in an environment where everything militates against risk-taking. Basic research *can* be justified because it helps to define the technology out of which weapons systems may develop; *new* defense systems are made up of fragments of *new* defense technologies coupled to an existing base. According to this view, 6.1 work is the "push" that really changes the technology base, with 6.2 and beyond as the "pull." Nor need basic research always precede the product development cycle; a military microelectronics facility producing customized chips for military customers, for example, may do fundamental research into the properties of matter as part of its design program.

Special-purpose Work

The in-house laboratory also exists to do work that is not of interest to commercial industry but is of interest to the military. A case in point is the kind of small-batch production of radiation-hardened chips done at a few labs. Such R&D serves two related purposes: it produces highly specialized chips in small runs for military customers and, more important, it leads to new technology for subsequent insertion into existing systems. The drafting of new specifications can, by itself, lead to new development projects. What is more, the effort to improve production cycles can itself lead to new technology: in areas like silicon-on-sapphire microelectronics technology, military labs are far ahead of industry.

Such special-purpose facilities help to tie industry to the work that is being carried on at military facilities. By pushing the state of the art, these facilities force industry to focus on applications of military interest, such as the radiation hardening of integrated circuits and the applications of indium phosphide and gallium arsenide technologies. By doing very advanced research, these small, specialized production facilities stimulate the *right* kind of work, so that it becomes available for industrial production.

User Support

For many labs, work does not end when they hand over technology to the buying organization. In this context, the term "laboratory" is something of a misnomer, applying as it does to the NRL and a few smaller institutions. The preponderance of service R&D facilities are product development or engineering centers, whose staff will often continue work to the fielding of a new system and beyond.

Viewed in this light, much of the research at the Naval Weapons Center (NWC), the Naval Ocean Systems Center (NOSC), and even NRL is done the better to support their principal customers or, as necessary, to provide quality control support to the contractor. Thus NWC was brought in by the Naval Air Systems Command to assist in redesigning the Sparrow—a medium-range, air-to-air guided missile that had run into serious problems when deployed in Vietnam; NRL has consistently sent its scientists and engineers in to support the fleet; and many Air Force R&D centers have sophisticated approaches to inserting new technologies in existing systems. Indeed, much of this technology insertion can occur indirectly: for example, a company may do development work under contract to an engineering center, adapt the new technology and sell it back to the military.

If stress has been laid on the role of Navy centers in supporting the fleet, it is because this is one of the features that most distinguish them from the other Services, especially the Air Force. Compared to the Navy, the Air Force uses its labs more exclusively for technology exploration and component work, and uses industry for bringing technology to production. The Navy, on the other hand, uses its labs in "full spectrum mode" for 6.1 through 6.4 (engineering development) work, and acquisition support and fleet support thereafter. The reason, as one Navy official explained, is that the Navy's mission "makes continuous support for industry necessary, because [otherwise] a contractor might have to go out on a carrier for six months."

Still, it must be said that much of the justification for military work conducted out of military facilities is somewhat after the fact. The current institutional arrangement of military R&D is more a matter of history than of cold logic. In fact, the two alternative models for technology development within the government were generated outside DoD, by NASA and the Atomic Energy Commission (AEC). Each model embodied a philosophy of how different research and engineering centers could be grouped in related fashion.

In each case, the critical decisions on how the agencies would operate were taken right at the beginning. NASA would operate through a network of field centers staffed by government employees who would define the work to be done, select the prime contractors, evaluate the work done and, if necessary, be prepared to go into the contractor's plant and take over.[5] By contrast, the AEC chose to work through a network of multiprogram laboratories operated under contract; in the case of the weapons laboratories, they would be part of a vertically integrated system combining research, weapons design, and production.

The important point is this: the institutional arrangements at NASA and AEC were matters of deliberate policy. By contrast, the military R&D establishment has grown haphazardly without the kind of fundamental decisions that NASA or AEC took. Unlike those agencies, the Services and the Office of the Secretary of Defense (OSD) have vacillated among a number of approaches: between building up labs as full-spectrum organizations, or separating generic technology base work from engineering and development; or between doing research loosely coupled to service missions and pressuring the labs to work only in mission-related areas. While DoD's stated policy is that its in-house labs shall maintain "a level of technological leadership that shall enable the United States to develop, acquire, and maintain military capabilities needed for national security," the actual policies of OSD and the services are somewhat less consistent.[6]

This inconsistency shows itself in organizational arrangements that (so to speak) require one part of the organization to work around the rest. Despite everything that militates against it (see ch. 4), some good work manages to get done. The problems that afflict military tech base work are those that afflict all very large organizations. In general terms, bureaucracies are "tentacular"; that is, if you make a mistake, be very sure that every hole is plugged so that it will never happen again. One official put it this way, tongue firmly in cheek: "Central is better. If you want to buy furniture, have one guy in charge of buying for the entire organization, even if you can go across the street and get the item at a much lower price."

In fact, that remark identifies one of the key flaws in the entire DoD technology development organization. At many labs, the technical director has no control over the most important support elements of his or her organization—the personnel office, the general counsel, the procurement people, possibly even computing services, all of whom report to the buying commands or headquarters.

But this is to anticipate the ensuing analysis of operations at military R&D centers. While one can generalize about the problems of the military labs, a better approach is to begin with specific issues and, in the light of those analyses, to derive some useful conclusions.

Personnel Management

Virtually every study of military laboratories has noted critical deficiencies in the way they recruit, train, and manage their professional staffs:

- Most of the larger laboratories experience difficulty in hiring and retaining qualified scientific and engineering personnel, especially highly qualified senior staff.

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[5] On the decision to create centers staffed by government employees, see Arnold S. Levine, *Managing NASA in the Apollo Era*, SP-4102 (Washington, DC: NASA Scientific & Technical Information Branch, 1982).

[6] U.S. Department of Defense, Under Secretary of Defense for Research and Engineering, Department of Defense Instruction 3201.3, Mar. 31, 1981, p. 2. Cited in Library of Congress, Congressional Research Service, "Science Support by the Department of Defense," December 1986, pp. 178-179.

- The government is at a major disadvantage in competing with industry and the universities for the best technical and engineering graduates.
- The job classification system requires elaborate position descriptions that have little or nothing to do with the positions being filled.
- The system makes it difficult to reward the good performers or remove the poor ones.
- Inflexibility in setting salaries means that pay is seldom commensurate with performance.

Lab directors do have some discretion to work within the system. Thus the Navy uses ''managing to payroll'' (MTP) as a discipline to keep from hiring too many people, while allowing trade-offs. MTP allows the naval centers to keep their dollars constant while changing the number of slots. From the Navy's perspective, the advantages of MTP are, first, that it gives technical directors flexibility in distributing work among different center employees and contractors; and second, that it helps to ''cleanse'' the centers by shedding work that they should not have taken on in the first place. Under MTP, centers can maintain a stable work force either by cutting back on contractors, or by carrying their people on overhead.

Most military R&D facilities have tried to make similar, piecemeal improvements within the current system. But two R&D centers have successfully attempted a more comprehensive approach, within the terms blessed by Title VI of the 1978 Civil Service Reform Act. Since 1980 the NWC (China Lake, CA) and the NOSC (San Diego, CA) have participated in a personnel experiment, with two other Navy centers as controls.

The China Lake experiment, as it is generally known, breaks with the standard Federal personnel system in four ways: 1) separate career paths, with distinct paths for scientists and engineers on the one hand and technical or administrative specialists on the other; 2) the consolidation of 15 General Schedule (GS) grade classifications into no more than 5 broad ''pay bands'' corresponding to career paths (professional, technical, administrative, technical specialists, clerical/assistant); 3) abbreviated position descriptions and standards; and 4) a much closer linking of pay to performance. Although the Office of Personnel Management (OPM), which oversees the project, originally designed it to run 5 years, Congress has extended it to 1990.[7]

Differences in the ways the two centers have implemented the China Lake experiment are minor compared to the similarities. At both NOSC and China Lake, pay is linked to the GS scheme of classification. There is a set formula for hiring junior professionals determined by each center's personnel office; at higher levels, supervisors set salaries according to the pay bands, with salary tables based on government-wide changes in GS pay scales. Each career path is a separate competitive path: if reductions in force occur at a center, they can occur only within specified career paths.

China Lake has been one of the most closely followed demonstration projects ever sponsored by the Federal Government. OPM has monitored the project since its inception, issuing annual progress reports and a comprehensive evaluation in 1986. In that report, OPM found that the project had largely succeeded in doing what it was intended to do. Compared to the control sites, personnel at the demonstration labs—employees and supervisors—perceived the system to be more flexible than the Navy's conventional performance appraisal system. In reviewing compensation systems, OPM concluded that the positive results it found seemed to have been ''strongly influenced by the introduction of broad pay ranges corresponding to the new classification levels . . . broader pay ranges provide greater latitude in making performance-based pay distinctions.''[8]

OPM identified other elements that, in the opinion of its staff, helped account for the project's relative success. One of these was the labs' involvement in developing their system. Another was that the system covered employees at a wide range of work levels, and a third was the protection of employees from any initial adverse impact, by a "buy-out" feature written into the project plan.

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[7] There have been many descriptions of the China Lake experiment. This account draws on several, including: U.S. Office of Personnel Management, Research and Demonstration Staff, Office of Performance Management, ''Status of the Evaluation of the Navy Personnel Management Demonstration Project: Management Report I,'' March 1984 and (same source) ''A Summary Assessment of the Navy Demonstration Project: Management Report IX,'' February 1986. The original OPM proposal is in *Federal Register*, Vol. 45, No. 77, Apr. 18, 1980, pp. 26504-26543. A good summary account may be found in Larry Wilson, ''The Navy's Experiment with Pay, Performance and Appraisal,'' *Defense Management Journal*, Vol. 21, No. 3, 3rd quarter 1985, pp. 30-40.

[8] U.S. Office of Personnel Management, ''A Summary Assessment,'' op. cit., footnote 7, p. VII.

The China Lake experiment was not designed to be cost neutral. That is, the Navy recognized that there would be certain start-up costs in moving to the new system. Once the system was in place, average salary differences between demonstration and control labs tended to flatten out, to the point that the difference among scientists and engineers diminished greatly or even disappeared after they had been on board 3 or 4 years.[9] But the ways in which the same pot of money was distributed were quite different. As OPM put it, "the initial salary gap is great enough that in any year the remaining demonstration v. control difference in the salaries of new and recent hires accounts for about 2 percent to 3 percent in additional demonstration payroll costs."[10]

One of OPM's most significant conclusions about China Lake was that although costs are controllable, "the decision to limit costs can substantially alter the results achieved. Unless organizations are willing to make some investment in the new systems, employees are likely to perceive they will gain no benefit from the systems, or that they will actually be penalized under the systems."[11] In fact, OPM concluded, total salary costs had risen by 6.0 percent (as of January 1986) over those of the control sites as a direct result of the project. Costs rose because the demonstration labs were offering to scientists and engineers starting salaries that were 17.5 percent higher than at the control labs, and because China Lake permitted greater salary increases within pay bands than would have been possible under the General Schedule.[12]

A May 1988 report by the General Accounting Office (GAO) confirmed many of these findings. GAO's general conclusion was that the project demonstrated that a pay-for-performance system could be implemented to the general satisfaction of many supervisors and their employees. Despite this qualified approval, GAO found that the OPM evaluation left many questions unanswered. In GAO's view, "the overall weakness of the China Lake evaluation was that when all is said and done, the volume of data that were either missing or non-comparable was quite large." Although GAO did not know the reasons behind the data problems, it determined that "they were of such magnitude that firm conclusions about project effectiveness cannot be drawn."[13]

The problems GAO cited included the non-comparability of the test and control sites and a lack of information on how and to what extent the project was implemented at the test sites.[14]

But this begs the question. Underlying the GAO analysis is the assumption that one is comparing a tentative demonstration with a system that is internally coherent and designed to address the same issues (but in a different way) which the China Lake demonstration was created to address. Leaving to one side the difficulty of evaluating so complex a program, the existing government personnel system is even more vulnerable to criticism. Speaking only of current hiring procedures, former OPM Director Constance Horner said that the system "is slow; it is legally trammelled and intellectually confused, and it is impossible to explain to potential candidates."[15] China Lake and a comparable demonstration project at the National Institute of Standards and Technology (NIST) (formerly the National Bureau of Standards) have a coherence and logic that the current system altogether lacks.[16]

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[9] Ibid., pp. 51-52.

[10] Ibid., p. 52.

[11] Ibid., p. VIII.

[12] In an update of its 1986 report, OPM concluded that the average salaries of demonstration lab scientists and engineers continued to grow relative to those of their control lab counterparts. This difference could *not* be explained by the effects of salary increases, since these were virtually identical at both kinds of site. Higher starting salaries for scientists and engineers, which were 18.7 to 29.1 percent greater at the demonstration sites, seemed to account for much of the differential. U.S. Office of Personnel Management, "Salary Costs and Performance-Based Pay Under the Navy Personnel Management Demonstration Project: 1986 Update: Management Report X," December 1987, pp. 3-6.

[13] U.S. General Accounting Office, "Observations on the Navy's Personnel Management Demonstration Project," GGD-88-79, May 1988, p. 29. These remarks were included in a letter from GAO to Senator Sam Nunn, Chairman of the Senate Armed Services Committee.

[14] In light of its findings, it is worth noting that GAO has instituted its own pay-for-performance system, with three pay bands corresponding to Grades 7 through 12, "leadership" positions at GS-13/14, and "managerial" posts at GS-15.

[15] Constance Horner, "Address to Career Entry Recruitment Conference," Washington, DC, June 23, 1988, p. 4.

What has the China Lake experiment really achieved? In one sense, it "demonstrates" just how inadequate the current personnel system is. Note that the experiment is now into its ninth year, with no immediate prospect of extending it to other government laboratories. A program that began under Carter and continued under Reagan awaits the Bush Administration for extension or termination. The Civil Service Reform Act that authorized the project provided no mechanism for extending it beyond its test sites. Assuming that the project is extended beyond 1990, the government may be faced with a successful experiment that will have no ramifications, unless Congress enacts proposals to extend the project to Federal laboratories generally.[17]

But if one concedes—as even GAO has done—that the China Lake experiment did what it was meant to do, its success is somewhat irrelevant to the problems of DoD laboratories. One could conceive of small-scale improvements to the current system even without instituting performance-based pay. After all, OPM has in place mechanisms that make it easier for agencies to hire qualified professional staff. Thus, agencies can now apply to OPM for authority to hire engineers directly, without an initial screening by OPM. OPM has delegated to agencies the authority to negotiate starting salaries with top-quality candidates for jobs at grades GS-11 and higher. On a pilot basis, OPM is drafting simpler standards that agencies can use to classify positions, including engineering positions. These new standards, OPM says, "will give agencies more flexibility to redesign work, to classify jobs and to write agency specific guides if needed."[18]

But the ultimate limitation of China Lake and similar proposals is that they simply divide up pieces of a pie whose overall size remains about the same. Salaries are adjusted within narrow parameters; despite increases at demonstration sites, OPM found that salaries for nearly all the occupations compared grew 5 to 19 percent less at those sites than did salaries for the same occupations in the private sector.[19]

In this respect, the NIST project is superior because it has the authority to adjust the salaries it pays its scientists and engineers to match those paid by the private sector for comparable work. And while its demonstration project is supposed to be cost neutral during the first of its 5 years, NIST can use the surveys as a device to narrow (if not close) the salary gap between itself—NIST salaries are already among the highest at Federal laboratories—and industry by work force attrition.

Even if the China Lake experiment were extended government-wide, it would take a long time to undo the damage wrought by the current system. Personnel issues cannot be isolated from other issues—funding, research planning, the acquisition of major systems, and the like. Among the elements not yet mentioned that affect the labs' ability to hire, promote, and retain are the periodic hiring freezes that affect most government institutions; the new Federal Employees Retirement System, which makes it easier for government workers with portable benefits to leave the government earlier; and cutbacks in travel budgets, which make it harder for lab officials to recruit. Compared to the larger DOE laboratories, which recruit from the top 10 percent of graduates from the major national technical schools, most DoD managers tend to hire locally—partly because of small travel budgets, partly because they are resigned to the unavailability of top graduates.

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[16] There are major differences in the design of the NIST and China Lake projects. Although it incorporates such concepts as pay bands and career paths, NIST has certain special features: direct-hire authority for all professional employees, an annual comparability survey of *total* compensation of NIST positions to similar positions in the private sector, cost neutrality, and recruiting allowances for professionals that NIST particularly wants to hire.

[17] There have been a number of legislative proposals to reform the Federal personnel system. OPM twice unsuccessfully introduced its own proposal for a "Simplified Personnel System," most recently in January 1987. A bill, S. 2530, introduced by Senator Jeff Bingaman (D-New Mexico) in June 1988 would extend the China Lake experiment beyond the two naval centers currently involved. S. 2530 would authorize between six and ten personnel demonstrations, of which four would be instituted at DoD and one at NASA. The bill would establish higher minimum rates of pay and an alternative compensation system based on comparable rates for comparable private-sector work.

[18] U.S. Office of Personnel Management, "Simplifying the Federal Manager's Job" (n.d.), p. 3.

[19] U.S. Office of Personnel Management, op. cit., footnote 12, p. II. OPM derived its salary-comparison figures from data provided by the Bureau of Labor Statistics.

But personnel issues extend beyond competing with the private sector for new hires. Retaining good employees in an environment where the work force is overgraded but underpaid is just as formidable a problem. Technical directors stressed the nature of the work itself as one of the strongest attractions for their best and brightest. Good people stay if the work is challenging, if they have the opportunity to do some basic research and publish their findings, if discretionary funding is available to start new work, and if the laboratory gives equal recognition to separate career tracks for researchers and managers.

Although many lab officials spoke of having "two-track" systems, the evidence for such is ambiguous. According to a survey by the Army Laboratory Command, lower-level engineers believed "that a scientist had to become a manager in order to get ahead in a government laboratory."[20] From the lab director's perspective, someone has to take on the responsibilities with which external organizations task the lab, as well as manage the larger programs that constitute its mission. Thus, inevitably, many scientists and engineers come under pressure from their superiors to take on work outside the disciplines in which they were trained. Sometimes, scientists and engineers make a successful transition into management. Other times, as one former government official said, "you take good engineers and turn them into lousy managers."

There is also a more insidious threat to the integrity of the professional work force. Throughout DoD laboratories, the increase in congressional oversight has gradually transformed the role of research executives, such as division heads and branch chiefs. Rather than managing projects or ensuring their technical quality, one of their principal jobs is now to insulate their bench-level people from the requirements with which Congress tasks the labs and their sponsors. In particular, the amount of oversight and paperwork appears to have increased the most at those laboratories where the bulk of the work is contracted out—thus forcing managers and other senior professionals into contract administration.

In sum, the personnel problems that afflict most DoD laboratories are not personnel issues in the narrow sense. They flow, rather, from the total environment within which professional staff and managers try to get their jobs done. Even where a center can attract the top graduates, it has to contend with problems that are not "personnel" at all: uncertain budgets, long lead times in building new facilities and procuring new equipment, and limits on the pot of discretionary funds available to start new work. The incentives for a new hire to remain permanently depend more on the total environment of his or her institution than on personnel management practices in the narrow sense.

Two more points deserve emphasis. The first is that the Federal personnel system creates some perverse incentives for retaining employees. Under the Federal Employees Retirement System, the better employees can take their retirement benefits and leave for industry and universities with many of their more productive years still ahead. At the same time, mediocre performers remain; under the China Lake system or Managing to Payroll, they can expect no major salary increases, but they also stand little risk of being terminated. Thus, a low turnover rate at a laboratory can be a sign of health or a portent of institutional decline.

The other point has to do with the optimal size of laboratories, an issue discussed later in connection with GOCO facilities. It may well be that there are too many DoD laboratories, and that many of them are too small ever to achieve critical mass. If an institution is too small, there will be too little flexibility for a few people to strike out into new territory, or for new ideas to spill over into research work. At smaller facilities, there may not be enough groups of two or three or four people delving into areas unconnected with their current missions but that might lead to new missions. Government institutions seemingly must have more than about 1,000 people before the kind of flexibility that makes for their survival exists.[21] Additionally, as weapons systems grow ever more sophisticated, the number of disciplines that a lab needs under one roof will increase.

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[20] U.S. Army Laboratory Command, "Innovative Personnel Practices," March 1988, p. 4.

[21] Hans Mark and Arnold Levine, *The Management of Research Institutions: A Look at Government Laboratories*, SP-481 (Washington, DC: NASA Scientific & Technical Information Branch, 1984), p. 70.

The question of a lab's optimal size bears directly on the retention of quality staff. Unless a lab is assigned a mission in one narrowly defined area—the Army's Night Vision Laboratory (Ft. Belvoir, VA) might be an example—it must have scientists and engineers drawn from a variety of disciplines. Even in that case, as a 1979 government report noted, "the development and enhancement of modern technologies is an inherently multidisciplined endeavor. The most narrowly focused of research activities today involve several professional disciplines as well as highly skilled technical support personnel."[22]

The DOE's weapons laboratories have become adept at instituting a matrix structure, whereby money is pulled away from divisions and moved into programs. The result is that there is more mobility within Energy labs like Sandia and Los Alamos than at most DoD labs. With some exceptions, a new professional hired at a DoD lab is likely to spend his or her career within the same research division or directorate. In contrast, professionals at DOE labs have more options: beginning their careers at (say) the lab's research division, they may move into mission-related areas, return to research, or move into management.

In fact, the DOE labs have done more to control personnel problems than virtually any DoD facility. For one thing, they have bypassed the entire issue of salaries comparable to those of the private sector. As a rule, salaries and personnel systems correspond closely to those of the contractor who operates the lab: the personnel system at Sandia National Laboratories is modeled on AT&T's Bell Labs, while those at Los Alamos and Lawrence Livermore National Laboratories are modeled on that of the University of California system. For another, the DOE laboratories tend not to hire for specific jobs. Their size and multidisciplinary capabilities make it easier for lab executives to move people to where they are needed and redeploy people as projects wind down.

Laboratory Management Issues: Funding

The ability of a government laboratory to accomplish its mission depends on the ways it is funded. The amount of funding obviously matters, but so does its predictability, flexibility, and the ability of lab managers to disburse funds once they become available. Laboratory executives say they prefer funding that is tight but predictable over larger but unpredictable funds.

At DoD labs, funding problems are at least as numerous as the personnel problems they aggravate. Funding is unstable, making planning and staff continuity on projects difficult; it is inflexible, in that most funds cannot easily be transferred to other accounts where they might be needed more; and monies must be spent during the fiscal year for which Congress appropriated them, preventing the buildup of contingency funds. This requirement affects DoD's ability to sustain long-term work.

Nevertheless, there are important differences in the way the services do their getting and spending—with the Navy centers obtaining their funding from the Naval Industrial Fund (NIF) and the Army and Air Force receiving money through line-item appropriations.

NIF is a shorthand way of saying that naval centers must recover the full cost of their operations. Industrial funding provides working capital for industrial-type activities, such as shipyards, the overhaul of aircraft, or running a laboratory. Under this approach, the activity pays all its expenses out of working capital and charges its customer the full cost of its products and services. Each industrial fund activity group has a cost accounting system specifically designed for its operations, to identify and accumulate the costs of their products or services.

This approach has important implications for the conduct of naval research, development, test and evaluation. First, because the NIF is a revolving fund, payments that naval centers receive from their customers should do no more than replenish the working capital fund that finances operations until payments are received. Second, in relation to their "buying" commands, naval centers are contractors *de facto* and *de jure*. A Naval center undertakes work for (say) the Naval Sea Systems Command on the basis of a contractual agreement that obligates both parties until work is completed. A facility like the NWC at China Lake has virtually no line-item budget authority. Instead, it operates like a Battelle or SRI International, which would go out of business if it had no customers.

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[22] Federal Coordinating Council for Science, Engineering and Technology, op. cit., footnote 6, p. 10.

A third, very important, feature of NIF is the asset capitalization program (ACP).[23] Effective fiscal year 1983, the Deputy Secretary of Defense approved asset capitalization as a way to fund the modernizing of industrial fund equipment. Under the program, equipment costs are recovered over the life of the asset by including depreciation costs in the rates charged to customers. The availability of ACP money strengthens the cash position of industrial fund, and helps fund managers avoid shortages.

Thus, naval engineering centers obtain work quite differently than a NASA research center or an Army laboratory—although Army research, development, test, and evaluation (RDT&E) was funded industrially at one time. At a facility like the NWC, the program offices serve as "shadow offices" to their counterparts in the prime sponsoring organization, which in their case is the Space and Naval Warfare Systems Command (SPAWAR). Note that this is *not* the principal buying organization for the center; its principal customer, accounting for more than half of its total obligational authority, is the Naval Air Systems Command. Although there are something like 3,000 customer orders in the system at a given time, some two dozen cover most of NWC's work.

In the view of managers at the Navy centers, industrial funding is an effective way of getting work done. Among its advantages are that it provides limited authority to start work on a sponsor's order prior to the receipt of funds, assists managers to control their resources better, enables the facility to finance and carry inventories of non-standard materials, permits the use of working capital for initially charging all costs, including 6.1 and 6.2 work, and serves to develop total costs for each task, including overhead.

Most Navy lab managers consider a recent OSD proposal to terminate NIF over the next two fiscal years potentially disastrous. DoD contends that industrial funds are more costly to operate than other systems, that their advantages have not been demonstrated, that industrial fund clients are not bona fide customers who can take their business elsewhere, and that as structured, the system makes DoD and congressional oversight difficult. The Navy, supported by GAO, disputes these assertions, claiming that NIF meets the criteria under which the Navy's research and engineering activities are financed.[24]

If NIF were terminated, the Navy would have several options. One would be to convert to a resource management system that combined customer-funded direct labor with Navy-funded overhead under an appropriate budget line item. This could be disastrous, in the view of some officials, because overhead becomes very difficult to defend in a competitive budget preparation environment. Alternatively, the Navy could adopt a resource management system with "applied overhead," which is identical to NIF at the macro level, except that it has no asset capitalization program. While the Navy could live with this arrangement, it would incur sizable one-time costs to convert its financial systems.

Compared to Army and Air Force labs, industrial funding gives the Navy a certain flexibility in starting and accounting for work. But it is still firmly part of the appropriations process, although at one remove. The start of work at a Navy lab still depends on its customers having the necessary obligational authority—and, if that money comes in late in the fiscal year, that it remains available to complete the work it is funding. Further, there are important areas of naval lab operations not covered by industrial funding, such as military salaries, non-appropriated funds, and military construction.

Military construction deserves special mention, since delays in new construction are one of the major obstacles to lab performance. This is the case for several reasons: as with other functional areas, those responsible for facilities management do not report to the lab technical director; lab requests for new facilities are thrown into one "pot" with other construction requests, and new facilities for labs generally have rather low priority. At some DoD laboratories, many facilities are 40 years or even older.

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[23] On the asset capitalization program, see U.S. General Accounting Office, "Industrial Funds: DoD Should Improve Its Accounting for Asset Capitalization Program Funds," NSIAD-86-115, May 1986.

[24] U.S. General Accounting Office, "Proposal to Change From Industrial Funding to Another Method," NSIAD-86-47, December 1986, pp. 1-2.

This is doubly unfortunate, because good facilities not only drive a lab's mission, but also attract good people. In turn, an excellent staff will, to a degree, generate good facilities. The process is self-perpetuating; people tend to generate new programs around the facilities, so that when an RDT&E organization matures, its roles and missions depend primarily on the facilities available: wind tunnels, clean rooms, anechoic chambers, simulators, and the like. As other authors have noted, ''facilities have a longer 'half life' than people. A facility like the 40-by-80-foot wind tunnel at [NASA's Ames Research Center] might be used for forty years, while an individual researcher will change his interests every three or four years and move on to something new. Thus a vigorous research and development program demands an efficient facilities development staff, more particularly where one facility serves a number of projects.''[25] By this criterion, few DoD laboratories have the power to develop facilities to keep pace with either the equipment that they will house or the missions they are designed to support.

Thus, DoD laboratories are subject to all the disadvantages and few of the advantages of facilities owned and operated by the government. But it is important to understand that these problems do not flow automatically from the status of these facilities as government-owned, government-operated institutions. Both the NASA centers and NIST have shown greater flexibility: NIST, because its role as lead agency in measurement science is highly valued by its government customers; NASA, because of the much stronger ties between the centers and their principal buyer, the headquarters program offices, than in the DoD system. At NASA, the centers largely define the programs that the agency funds. At DoD, by contrast, the relation of the R&D infrastructure to the buying commands is much less certain.

The next section describes alternative approaches to developing technology—those represented by GOCO facilities of the DOE and the somewha similar FFRDCs under DoD.

GOVERNMENT-OWNED, CONTRACTOR-OPERATED FACILITIES: AN ALTERNATIVE MODEL

Introduction

The GOCO facilities are an unparalleled resourc for the United States. In particular, the nine multiprogram, or ''national'' laboratories represent one o the heaviest investments in basic and applie research made by the United States or any othe country. Besides conducting about 70 percent of th DOE's weapons development and a quarter of it energy-related research, the national labs have othe roles. As systems engineers for DOE, as consultant to State and local governments, and as stewards o unique facilities, the labs contribute in many ways t the Nation's technology base.

From their inception, all the multiprogran laboratories have been government-owned and contracto operated. The Atomic Energy Commissioners chos this course, although they were not barred from operating their own laboratories; indeed, the Atomi Energy Act of 1946 authorized ''a program o federally conducted research and development.'' According to Harold Orlans, the AEC contracte with private organizations as the principal means o ''retaining a degree of normalcy and freedom in the evolving system of nuclear science and industry.''[26] By contracting with outside groups, AEC could keep them informed about highly classified activities tha would normally be confined to official circles, and bring to the government experience and advice no normally available to it. Orlans concluded that thi decision helped, as much as anything, ''to keep the AEC more alive and alert, administratively and technically.''[27] The result was an arrangement tha has no counterpart in the Federal Government, save for the contract between NASA and the Californi Institute of Technology to operate the Jet Propulsion Laboratory.

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[25] Watt and Lyons, op. cit., footnote 21, pp. 65-66.

[26] Harold Orlans, *Contracting for Atoms* (Washington, DC: Brookings Institution, 1967), p. 5.

[27] Ibid., p. 9.

Before turning to the applicability of the Energy model to DoD institutions, something should be added about FFRDCs like Lincoln Laboratory and university-affiliated research centers like the Applied Physics Laboratory (APL) of The Johns Hopkins University.[28] DoD sponsored these centers for much the same reasons that DOE chose to operate its national labs through contractors: the Services sought independent outside expertise from organizations unfettered by many Federal regulations; they wanted to develop long-term relations with such organizations; and they specifically wanted to deal with institutions tied to the university community. The 30-year collaboration between the Navy and the Applied Physics Laboratory on the Fleet Ballistic Missile Program shows how effective such a special relationship can be.

The main difference between contract centers like APL and a DOE laboratory is that the former are privately owned organizations working for a primary sponsor. At APL, for example, Johns Hopkins owns the land and the buildings—although the Navy, APL's prime sponsor, furnishes the equipment. There are other differences of degree rather than kind. Compared to the DOE weapons labs, which have their own audit organizations, FFRDCs are audited regularly by the Defense Contract Audit Agency (DCAA). Additionally, many centers have to go through special procedures to avoid the full weight of Federal regulations. For APL to avoid the broad mandate of the Competition in Contracting Act for competitive procurement, the Navy's SPAWAR must draft a "justification and approval" which the Assistant Secretary of the Navy for Shipbuilding and Logistics ultimately signs.[29]

Although these contract research centers perform some of the functions of DOE's national laboratories, there are significant differences. One difference has to do with areas of emphasis: Compared to the many functions of the larger national laboratories, the FFRDCs and university affiliates tend to concentrate on systems integration and engineering services. They are more likely to work almost entirely for one sponsor, and to devote most of their resources to a few programs, than the national laboratories are. While the same could be said of DOE's weapons laboratories, their size, their diversity, and their capacities for advanced research make them a more appropriate model for DoD's consideration.

The GOCO Relationship at the Department of Energy: Contractual Arrangements

The organization and operation of the multiprogram DOE labs' are in dramatic contrast to those of labs operated by DoD employees. In the former, we find the vertical integration of research, development, and operations; a long-term relationship with the sponsoring agency; a critical mass of scientific and technical disciplines; and (compared to DoD) much greater flexibility in moving people between divisions and projects.

Although superficially complex, the administrative relations between the labs and DOE are actually much simpler than those at DoD. Through its staff and program offices, DOE headquarters in Washington sets broad policy and develops the overall budget out of which funds to operate the labs will come.[30] Eight field operations offices monitor the operating contracts, although their roles encompass much more. Finally, the labs carry out broad programs of research and technology development within the guidelines approved by headquarters.

Arrangements between DOE and its contractors vary within narrow limits. Management and Operating contracts normally run for 5 years, with the cognizant operations office performing a "compete-extend" analysis before the contract expires. Compared to standard commercial contracts between a Federal agency and vendors, the terms are more general and until recently were based mainly on reimbursable costs. Thus, AT&T manages Sandia on a no-profit, no-loss basis; the contracts for Los Alamos and Lawrence Livermore National Laboratories reimburse the University of California for operating costs and award it a management fee. More recently, at Oak Ridge National Laboratory, DOE has instituted a cost-plus-award-fee arrangement, in which the contractor, Martin Marietta Corp., receives a special fee based on performance.

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[28] U.S. General Accounting Office, "Competition: Issues on Establishing and Using Federally Funded Research and Development Centers," NSIAD-88-22, March 1988.

[29] Johns Hopkins University, Applied Physics Laboratory, "Report to The Johns Hopkins University Trustees Committee on the Applied Physics Laboratory," March 1988, p. 7.

[30] For purposes of contract administration, the field operations offices located close to the labs oversee them. For purposes of program planning and institutional management, the nine multiprogram laboratories are "administratively assigned" to two cognizant program offices. The Assistant Secretary for Defense Programs oversees the Idaho National Engineering, Lawrence Livermore, Los Alamos, and Sandia National Laboratories. The Director of Energy Research is the "cognizant secretarial officer" for the Argonne, Brookhaven, Lawrence Berkeley, Oak Ridge, and Pacific Northwest National Laboratories.

If one looks at these contracts after reviewing a standard contract between DoD and one of its commercial suppliers, they seem extraordinarily broad. Here is virtually the entire scope of work in the contract for managing Los Alamos National Laboratory:

> Work under this contract shall, in general, comprise research, development and educational activities related to the nuclear sciences and the use of energy in mutually selected military and peaceful applications, engineering services, and such other activities as the parties may agree upon from time to time . . .
>
> Due to the critical character of the work from the standpoint of the national defense and security, it is understood . . . that very close collaboration will be required between the University and DOE with respect to direction, emphasis, trends and adequacy of the total program.

How can anything so vague serve as the basis for operating a laboratory with an annual budget of $900 million? There is no single answer; instead, there are several reasons that this contract is a successful instrument for managing a national laboratory. One is that there is much more to the contract than the statement of work just cited; there are, in fact, numerous powers, especially the power of the purse, by which DOE fleshes out the very broad mandate just cited. Another reason is that after 40 years' experience of working together, both parties understand the terms very well. By itself, the GOCO contract does not lead to a long-term relationship; it presupposes it.

A special feature of the contracts between the University of California and DOE is the provision that work shall be set by mutual agreement. These "mutuality clauses" are unique, although at on time NASA had such a clause in its contract wit CalTech to operate the Jet Propulsion Laborator (CalTech has an R&D contract with NASA, not a operating contract for administrative services.) To degree, the mutuality clause gives a false impre sion, since it implies that DOE may unilaterally tas other laboratories that do not have such a claus There is actually a very complex give-and-tak between all of the multiprogram laboratories, thei sponsors, their clients (including DoD), and th universities. The mutuality clause simply affirms th understanding that runs through all of these con tracts: that DOE is tapping the expertise of outsid organizations to run the labs; that this expertis cannot be used effectively if DOE elects to micro manage the contractor; and that the contractor mus have freedom to select the technical approach mos effective in carrying out the lab's mission.

In this system, the operations offices are muc more than contract administrators. This is why DOE rejected a 1981 recommendation by the GAO tha the operations offices report directly to each lab' cognizant program office, rather than to the Department's Under Secretary. DOE officials contende that such a proposal would not only require a hug increase in Federal staffing, but would lead to "th balkanization of the field structure."[31] A mor compelling justification for leaving the field structure intact—as DOE did—is that the structure of th operations offices mirrors the vertical integration o the Department as a whole. For example, beside overseeing the Sandia and Los Alamos laboratories the Albuquerque Operations Office administers widely scattered weapons production facilities an the system for transporting all government-owne special nuclear materials.

The GOCO Relationship at the Departmen of Energy: Complying With Federal Norm

How far are the GOCO laboratories bound b Federal policies? There is no simple answer, perhap because neither DOE nor its contractors wish to b locked into anything too definitive. Yet there ha been a gradual shift over the past decade, with DOE trying to get the labs to conform more closely to legislation and regulations.

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[31] U.S. General Accounting Office, "A New Headquarters/Field Structure Could Provide a Better Framework for Improving Department of Energ Operations," EMD-81-97, Sept. 3, 1981. See especially the comments of Assistant Secretary for Management and Administration William Heffelfinge at pp. 43-49.

The official view reflected in DOE directives and in congressional legislation is that the labs' status does not exempt them from complying with the spirit of Federal policies. As stated in an opinion of the Deputy Comptroller General, the labs must comply with "the Federal norm":

> It is our view that while Federal statutes and regulations which apply to direct procurement by Federal agencies may not apply *per se* to procurement by prime operating contractors . . . the prime contractor's procurements must be consistent with and achieve the same policy objectives as the Federal statutes and regulations. This, we believe, is what is meant by the "Federal norm."[32]

While a laboratory like Sandia follows AT&T procurement and personnel management policies, it is also bound by a variety of regulatory constraints. These include DOE acquisition regulations and directives that apply the Federal Acquisition Regulation to departmental entities, the Buy American Act, and prevailing-wage legislation on Federally subsidized construction contracts. As Federal contractors, the national labs also come under the supervision of the Labor Department's Office of Federal Contract Compliance Programs.[33]

On the other hand, the labs are exempt from a number of requirements that bind Federal agencies, among them formal advertising, set-aside programs, and the Competition in Contracting Act. Although major purchasers of supercomputers, the national laboratories are also exempt from complying with the Brooks Act, which governs the acquisition of computers and telecommunications equipment, at least as it applies to scientific computing. The situation is less clear for administrative and general-purpose computers; the consensus at the labs is that they must sponsor full and open competition for these machines. Finally, because Sandia and other facilities have their own audit capabilities, they do not require the services of the Defense Contract Audit Agency in monitoring their own contracts. Lab officials believe that they can handle small and medium-sized procurements much faster than DCAA can, although there is evidence (see below) that procurement lead times have increased substantially at the national labs.

These exemptions affect the labs' operations in many ways. First, they enable the labs to build long-term relations with industry in a way not possible for Federal agencies bound by the Competition in Contracting Act. Second, the labs find it expedient to comply with the spirit of the law, even when they are not bound by the letter. Thus the weapons laboratories set aside a substantial number of smaller procurements for minority-owned small businesses. For example, under pressure from GAO, Oak Ridge National Laboratory dropped its percentage of sole-source procurements from 50 to 20 percent. Third, these exemptions make it possible for the labs to function; to impose the full weight of Federal regulations would undermine the rationale for having them run by contract.

One area where the labs are free to set their course is in personnel management. The personnel system at each laboratory corresponds to that of the prime contractor because, as one official explained, "in a GOCO you have not only the people, but also the organization's management system." There are no assigned slots at DOE labs, and the very best technical people can make as much as $95,000, although a lower figure is more usual. The most senior executives at the weapons labs earn between $100,000 and $150,000, roughly twice what their counterparts at the military labs earn.

The principal constraint on the willingness of a laboratory's prime contractor to set the highest salaries is the DOE review triggered at the $60,000 threshold; the local operations office has approval authority up to $70,000, and DOE's Office of Administration up to $80,000, with higher salaries requiring the Director of Administration's approval. Additionally, at some laboratories, DOE approves the appointments of the most senior executives.

DOE also approves facility-wide salary increases, based on cost-of-living adjustments, recruitment and retention rates, and the like. The facility proposes an increase to the cognizant operations office, which forwards the proposal with its recommendations to headquarters. For its part, the Office of Administration sponsors generic surveys of scientific and technical salaries. DoE is now developing criteria to remove individual salary reviews and convert to more "systemic" approaches to determining appropriate levels.

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[32] Decision of Deputy Comptroller General in protest of Piasecki Aircraft Corp. (B-190178, July 6, 1978), p. 10.

[33] Alone among DOE labs, Sandia has to file its accounting system with the government's Cost Accounting Standards Board.

Although practice varies from lab to lab, there is a certain uniformity in their hiring and promotion policies. When officials say that "there are no assigned slots at DOE laboratories," they do not mean that people move randomly from assignment to assignment. What they mean is that laboratories do not hire for specific jobs. Instead, they hire people with the technical disciplines that fit the laboratory's mission, and who give promise of performing well in a number of environments. Again, many labs like to move their "high-potential performers" within and between program divisions, especially those individuals with management potential.

The laboratories can hire and move around the best people because of their sheer size. Each of the weapons labs has about 8,000 employees and, while this creates problems of its own, the number and diversity of projects does make it easier to attract and retain the top engineering and scientific graduates—some of whom the labs hire on the spot. In particular, lab officials note that facilities are a key selling point in hiring and promotions. Although layoffs do occur, the labs can keep them fairly small, since they have other options not available to DoD laboratories, such as finding slots at production centers for lab employees no longer needed at the main facility.

The personnel practices that DOE ratifies have made the national labs far more competitive than most of those staffed by government employees. Thus, salaries are far more in line with industry and the universities; the surveys sponsored by DOE help to keep salaries realistic. Moreover, the labs recruit aggressively. Most of the larger ones recruit nationally and hire directly—something government labs are only beginning to do—and can attract the top 10 percent of graduates from the best engineering and technical schools.

Funding Arrangements and Work for Others

The three weapons labs receive level-of-effort funding for Defense programs. DOE allocates funds to each institution annually, based on its mission and the size of its staff. When the money becomes available to the laboratory, each program or division director negotiates with the lab director for a portion of the funds. But unlike many government labs, DOE facilities do not obtain their funds in one lump sum. Instead, they receive money from hundreds of separate contracts with other DOE components—the headquarters program offices—each of which specifies the task covered by its agreement. In this respect, the closest government analog is the NIF described earlier.

DOE-sponsored work is funded with "no-year" monies, available until spent. This does not mean that the labs have complete discretion in scheduling outlays. DOE provides budget outlay guidance on when money shall be spent during the fiscal year, and DOE weapons labs must obligate DOE funds to within 1 percent of allocation. But as one DOE laboratory executive observed, "it is the technical discretion of the lab management (not *accounting* discretion) which is crucial."

Other funds are obligated on a project basis by the end of the fiscal year, like those for DoD non-nuclear programs, although some DoD money for R&D is 2-year funding.

Consider how this system works at one weapons facility, Sandia National Laboratories. Its principal mission is research, development and engineering of the components of nuclear weapons (other than the nuclear explosive). In light of this mission, Sandia executives regard their technical programs as having two components: a technology base (basic and applied research, computing, analytic techniques, advanced components) and deliverables (materials fabrication, system design, quality assurance, stockpile surveillance, nuclear safety). It is this twofold mission that drives the program and determines the kinds of work Sandia will take on, particularly from non-DOE organizations.

For its purposes, Sandia's no-year budget authority has two advantages. First, it enables the lab to let contracts beyond the current fiscal year; and second, it allows long-term planning, even though DOE will direct the lab through budget outlay guidance on what may be spent in a given year. Beyond that, Sandia officials can view their funding in different ways. In terms of sponsorship, DOE defense-related funding in fiscal year 1988 accounted for 60 percent of total operating funds, with other energy-related vork accounting for between 9 and 10 percent. The emainder of Sandia's funds came from reimbursable work from outside organizations—the impor-ant category of "work for others."

Sandia's policies on work for others follow DOE guidelines. Briefly, Sandia will not undertake work f it interferes with DOE weapons programs. Even if esources are available, Sandia will not commence vork unless it meets several criteria: The work must e of national and technical importance, match the ab's mission and capabilities, avoid competition vith the private sector, and complement existing DOE programs with integrally related work. Where Sandia participates in reimbursable programs, it ncorporates DOE's policy of full cost recovery. Sandia will seek to recover all costs including labor, irect charges, overhead (the lab charges the same ates to DOE and outside organizations), and general urpose equipment.

Like the other two weapons laboratories, Sandia lso applies a surcharge—a tech base "tax" on all vork for others—that it uses to fund new, long-range esearch. At Sandia the tech base tax currently upports 70 people, most of whose work runs for up 3 years. Note that this tax is only a portion of what andia spends on tech base work. According to DoD unding categories, approximately 8.4 percent of andia's 1988 budget went for 6.1 work and another 7.4 percent for 6.2, or exploratory development.[34] hus, Sandia is effectively spending just over a uarter of its $1.1 billion budget on tech base—a far igher amount than any DoD laboratory or engineer-g center, save the Naval Research Laboratory, ends.

The major difference between DOE and DoD licy on work for others is that the DOE multipro-am laboratories consider it a normal and desirable rt of their missions, while the latter does not. For D, work for others—primarily non-defense work civilian agencies—is a distraction from the labs' ssions and to be confined within narrow limits. r many years, DoD has had a policy of limiting h work to 3 percent of professional staff-years at ividual laboratories. Since DoD labs are con-ined by total personnel ceilings and are not allowed to keep revenues for work for others, any work done for external users comes directly at the expense of their DoD clients. At the DOE labs, by contrast, work for external agencies is much more open-ended: up to 20 percent of operating budget for Energy Research labs, and as much as 30 percent for the weapons labs.

This raises a fundamental question about the missions of the multiprogram labs: Why are they so eager to diversify? The easy answer is that as self-consciously "national" facilities, the laboratories regard diversification as an essential part of their mission. But there is more to it than that. These facilities have the preconditions for successful diversification. The first is the presence of second parties willing to sponsor a laboratory's venture into new fields, just as industry sponsored Sandia's work in drilling technologies, or Du Pont worked with Argonne National Laboratory on neutron diffraction studies of catalysts, or SDIO funded work at Los Alamos in directed-energy weapons.

Next, lab executives believe that while their organization's mission remains relevant, current programs do not exhaust the organization's capacity to carry it out. And not least, there are few institutional barriers to prevent laboratories from taking a broad view of their missions. Here, DOE has played an important part by its policy of permitting work for others, bringing in outside scientists and engineers for advice and joint ventures, and improving conditions for cooperative work. Indeed, the removal of obstacles may accomplish more than well-intentioned, but largely fruitless, efforts to stimulate two-party ventures.

This philosophy has implications for the defense tech base. As funding for nuclear weapons shrinks, DOE laboratory executives want to involve their organizations more closely in nonnuclear defense work. Diversification protects existing jobs and the ability to hire fresh graduates. Their laboratories, so their argument would run, are already working in these areas and have the experience to move into related fields. DoD funding for nonnuclear work is actually growing much faster than DOE funding is; at Lawrence Livermore, DOE funding between fiscal years 1982 and 1986 increased by 34 percent—

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[34] Information supplied by Sandia budget and program officers.

a real annual growth rate of 1 percent—DoD funding, by 256 percent.[35]

The labs can bring their enormous resources to bear on the most important technical problems; their nondefense work often has defense applications; and much of the technology that the weapons labs have developed for SDI can be transferred to tactical battlefield problems. Further, the enormous computing power at the labs—Los Alamos alone has computer power equivalent to 60 Cray-1s—is a resource for expanding the defense tech base in a much more sophisticated way.

In sum, the DOE's multiprogram laboratories may serve as one (not "the") alternative model to facilities owned by the government and operated by its own employees. They have avoided the rigidity of government personnel classifications and much (though not all) of its regulatory apparatus, and they have benefited from DOE's level-of-effort funding. They have the critical mass to move on several fronts simultaneously—although their size, as will be seen, may be a double-edged sword. The final section of this chapter examines the relevance of the DOE's GOCO facilities, and comparable federally funded R&D centers, to the problems of military laboratories.

SUMMARY AND CONCLUSIONS

Growing dissatisfaction with the operations of DoD labs has led to proposals that some of them convert to a GOCO status. In substance, this is what the DSB tentatively proposed for some labs in its 1987 summer study.[36] And in one sense, certain parts of DoD might accept such a transition. The Services have long relied on outside laboratories for sophisticated exploratory work. One thinks of the establishment of the Aerospace Corporation and Lincoln Laboratory as contract research centers for the Air Force, and the reluctance of the Navy's Strategic Systems Program Office to use naval laboratories in developing the Fleet Ballistic Missile in the 1950s and 1960s. Since the early 1970s, DoD in general and the Air Force in particular have moved to reduce the proportion of basic and exploratory research carried out by government employees, with the results noted in OTA's earlier Special Report on the Defense Technology Base.[37] To a degree, Service skepticism about the value of their own laboratories becomes a self-fulfilling prophecy.

The ultimate justification for converting a government facility to contractor operation is that it more effectively provides the government with a product or service, while ensuring that inherently governmental functions are carried out by civil servants. The remaining sections of this chapter weigh the virtues and drawbacks of this approach, in light of what is known about the operation of DOE's national laboratories.

Do contractor-operated facilities have greater management flexibility than in-house government facilities? What are the advantages and disadvantages, to the government and its operating contractors, of GOCO arrangements?

The evidence is unequivocal in personnel management but ambiguous elsewhere. Clearly, the DOE laboratories have much greater freedom than DoD facilities to hire directly from the universities, to pay salaries comparable to what industry and the universities pay for comparable positions, and to move people through the organization with relative freedom. Because the laboratories' personnel systems reflect those of their operating organizations, they tend to be less bureaucratic and more attuned to market conditions than the generality of government centers.

Some of this flexibility carries over into budgeting and program management. It should be noted that a significant portion of the labs' funding is for tech base work and that, within broad guidelines, much of their manpower is earmarked for work for others. Much of this work is, in a sense, diversification *within* the laboratory's primary mission, rather than *outside* it. Thus at Los Alamos a large proportion of work for others is sponsored by DoD, although some of it, as in laser technology, may have important commercial applications. There are also programs, like Lawrence Livermore's work on *in situ* coal gasification, which grew out of AEC research into the peaceful uses of nuclear explosives.

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[35] U.S. General Accounting Office, op. cit., footnote 28, p. 13.

[36] Defense Science Board, op. cit., footnote 1.

[37] U.S. Congress, Office of Technology Assessment, "Ch. 6—Managing Department of Defense Technology Base Programs," in *The Defense Technology Base: Introduction and Overview—A Special Report*, OTA-ISC-374 (Washington, DC: U.S. Government Printing Office, March 1988).

Clearly, the labs benefit from a management structure that enables the government to achieve its ends through a quasi-industrial system. What the operating contractors derive from this arrangement is less clear. At one extreme, AT&T, in running Sandia, and Du Pont, in operating the Savannah River Plant, are essentially working *pro bono*.[38] At the other, Martin Marietta is operating Oak Ridge National Laboratory for commercial reasons. It wants the award fee, it wants access to Oak Ridge personnel, and it wants access to technology—although Martin Marietta gains access to technology developed at Oak Ridge on terms no better than other corporations receive.

In an intermediate category are the labs operated by universities: Los Alamos, Lawrence Livermore and Lawrence Berkeley by the University of California; Argonne by the University of Chicago; and Brookhaven by Associated Universities, Inc. Although the University of California receives a management fee for operating its laboratories, this is not the main reason for the long-term relationship it has had with AEC and DOE. From the University's perspective, the laboratories enable it to do one of the things it exists to do—research. The laboratories offer matchless opportunities to do "big science," to use unique facilities, and to develop research ideas. At some university-operated laboratories, a sizable number of professional staff hold joint appointments, while many graduate students take summer jobs that ultimately lead to full-time positions. In these and numerous other ways, the universities gain at least as much as they put into running the laboratories.

There are, however, three disadvantages to the GOCO arrangement as DOE has adopted it. The first, the sheer size of the Energy weapons laboratories, was not inherent in the GOCO status. Rather, it stemmed from the Atomic Energy Commissioners' decision to make the laboratories full-spectrum institutions tied to the production facilities. Although this arrangement worked well for many years, it became more and more difficult for management to stay intellectually on top of institutions of the size of the weapons labs. All of them have now placed their own ceilings on institutional size, although this owes as much to the constraints of Gramm-Rudman-Hollings, and the likelihood that arms negotiations will lead to major changes in programs, as it does to a belief that a given laboratory has reached its natural limit.

Another problem with GOCOs is a certain lack of accountability. True, the operations offices are supposed to oversee the labs and production facilities, but evidence is mounting that the oversight has not gone far enough. Perhaps the evidence is stronger at production facilities, like the problems with reactors and nuclear wastes at the Savannah River and Rocky Flats Plants, than at the laboratories themselves. Weapons labs like Lawrence Livermore and Los Alamos oversee each other to some extent; this competition does not exist in the production sector. What seems to have developed over many years is a relationship between the government and the operating contractor, with virtually no continuing external oversight since the demise of the congressional Joint Committee on Atomic Energy in the mid-1970s.

This leads to the third problem, the abdication of technical responsibility by the government. Because the AEC elected to contract out almost all of its technology development, it happened that virtually all of the scientific and engineering expertise resided in the laboratories, with the headquarters organization at a real disadvantage in evaluating the laboratories' technical programs. This did not mean that headquarters or the operations offices could not overrule something the labs wanted. They could—but for administrative, financial, and political reasons, not technical ones. Just as AEC turned over research and development to outside organizations, so it also turned over much of its evaluation to outside advisory panels. In this respect, DOE is a lineal descendant of the AEC.[39]

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[38] In light of Du Pont's decision to withdraw as operating contractor, the DOE has awarded a contract to Westinghouse to operate Savannah River when Du Pont's contract expires in 1989.

The experience of the DOE weapons laboratories confirms the thesis that "the technical capability to do something is often the trigger that causes the establishment of a national policy based upon that capability."[40] This is true of the DOE weapons labs in a way that it is not of any DoD lab, except for the Naval Research Laboratory and a few engineering centers. And yet, because neither AEC nor DOE had any independent technical organization of their own, they had to defer to the labs on the technical merits of strategic weapons. It may well be that the development of many weapons programs or the creation of a civilian nuclear power industry would have occurred very differently had AEC sponsored an in-house organization to evaluate its contractors' proposals.

Do GOCOs tend to become more like government labs, since they face the same pressures to account for the use of public funds? To put it differently, do GOCOs develop analogs to Federal policies in acquisition, information management, and personnel, thus losing the flexibility that contractual status confers?

There does indeed seem to be a rule that, with time, contractor-operated and government-operated laboratories tend to become more like each other, because both are accountable for their use of public funds. In practice, no Federal agency has been willing or able to give its contractor-operated facilities complete independence to set policies within the framework of their missions, even when there were no specific regulations to prevent this. Nor does DOE's delegation of "inherently governmental functions" to the national laboratories contradict this. An agency can delegate those functions, while micromanaging its facilities in every other respect.

As asserted by the Deputy Comptroller General (quoted earlier), the government's position is that even when a contractor-operated facility is exempt from certain regulations, it must still comply with the "Federal norm." For instance, the national labs may not be directly subject to the Federal Acquisition Regulation; indirectly, they comply with it through regulations that DOE, their prime sponsor, imposes. Again, independent centers like APL need special waivers exempting them from full and open competition; must be prepared to respond to outside audits from different agencies; and must fine-tune their accounting systems to reflect the separate types of appropriations from which their funding originates. All of this adds to administrative overhead and to the demands on technical staff to shield bench-level workers from government paperwork.

GOCO facilities react to these demands in several ways. One is to comply with the spirit of government policy without being bound by its letter. This is why some DOE labs voluntarily synopsize their procurements in the *Commerce Business Daily*, reserve procurements for small businesses, and try to limit the number of sole-source contract awards. Another approach is to justify a deviation from Federal policy for special reasons, as the Energy labs do when they apply for authorization to purchase supercomputers.

For all that is known about the GOCO facilities, it is surprisingly difficult to acquire quantitative information about their operations, partly because DOE laboratory contractors are reluctant to supply the information, and partly because DOE tends to treat it as proprietary. The little that is known suggests that the advantages of a GOCO operation may be overrated. True, at Los Alamos, according to a government source, the contract staff can annually handle some 45,000 small purchases—those under $5000—over the phone. However, anecdotal evidence suggests that lead times at some of the Energy labs are at least as great as those at the larger military labs, and in some cases greater. To the extent that this is true, a GOCO institution is no guarantee against micromanagement and the kind of inflexibility found in government organizations.

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[39] Some observers have noted that DoD suffers from the same problem, in that the headquarters organizations that sponsor the work of in-house laboratories may also lack the technical expertise to judge the performance of these labs. The difference is that DoD executives did not deliberately turn over almost all of the military laboratories and related R&D operations to outside organizations, as the Atomic Energy Commission did with its labs, which were contractor operated from the start.

[40] Manfred Levine, op. cit., footnote 21, p. 221.

How and in what ways do GOCOs differ from government-operated laboratories in their ability to transfer the results of their 6.1, 6.2, and 6.3 programs to user agencies?

Again, the GOCO DOE laboratories show a much greater ability to move from basic research down the spectrum of technology development. DOE GOCOs are closer to the ultimate application than DoD labs are. Specifically, the weapons labs' responsibility extends from basic research to the retirement of weapons in the national nuclear stockpile. As mentioned above, the labs are only part of a vertically integrated complex that extends from basic research through the production of weapons-grade materials to the assembly of the weapon itself. In DoD, by contrast, the process by which technical work at the laboratories eventuates in operating systems is much harder to trace.

The very depth of expertise at the DOE weapons laboratories has two notable effects. The first is their commitment to a substantial amount of basic research and advanced exploratory work. Where a DoD facility might do only enough exploratory research to keep abreast of technology—keeping, as it were, a window on the world—the national laboratories tend to be more aggressive. They can afford to be: Where expertise at a DoD lab might go to a depth of two or three persons, at the national labs it can encompass an entire branch working in leading-edge technologies. Second, weapons-related work and nondefense programs cannot be segregated in terms of research. There is a constant give-and-take in these areas that leads to new ideas and new applications. Thus, the Los Alamos Meson Physics Facility (LAMPF) was originally designed in 1967 for research into the structure of the atomic nucleus. That research led, a decade later, to the spinning off of a separate group, leading in turn to neutral particle beam work that became a core technology for SDI.

In sum, the national laboratories have the resources to develop aggressively their portion of the defense technology base. In their operating agreements, DOE specifically recognizes basic research as a function that needs no extraneous justification. Beyond that, the interplay of technologies, the respect the university community has for the laboratories, and the tech base tax that the labs place on work for others, give them a marked advantage over the DoD labs in technology development.

What mechanisms can both kinds of institutions use to diversify within their basic missions?

Because the DOE laboratories have construed their missions in the broadest way, they have managed to diversify within, rather than outside, those missions. A more fundamental difference between Energy and Defense laboratories is that the former consider such diversification an integral part of their missions. The latter have diversified in response to directives from organizations external to the laboratories—the Service commands or OSD. Thus, the Army Laboratory Command developed a strategy for investing in next-generation and "notional" systems; and the Air Force sponsored Project Forecast II as part of its tech base strategy. Much of the military's tech base work will occur outside its own laboratories, while the reverse is true for the DOE.

Given the capabilities of the DOE weapons labs, it would be surprising if their primary mission did not spill over into related areas. Siegfried Hecker, Director of the Los Alamos National Laboratory, has put it succinctly. At the weapons labs, "nondefense basic and applied work is done in an environment oriented toward national defense. Thus, multiple payoffs are common and occur quite naturally. While contributions are made to the solution of nondefense problems and significant additions are made to the international scientific knowledge base, considerations of potential defense applications of research results come as a natural by-product."[41]

This approach has led the DOE laboratories to move increasingly into nonnuclear defense work. Although the DOE technology base developed separately from that of DoD, the two are converging. Here, too, Los Alamos has moved aggressively: applying (as mentioned before) LAMPF to the neutral particle beam program for SDI; working with the Army, the Marine Corps, and DARPA on the armor/anti-armor program; and investigating the uses of free-electron lasers for ground- and space-based weapons. Given the Energy labs' computing power, they can apply sophisticated modeling to the problems they choose to attack.

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[41] Siegfried Hecker, Los Alamos National Laboratory, "Review of Management of the Nation's Defense Technology Base," testimony at hearings before the Subcommittee on Defense Industry and Technology, Senate Armed Services Committee, Mar. 14, 1988, p. 15.

If the experience of the DOE laboratories demonstrates anything, it is that the greater the depth of expertise, the greater the ability to apply it to problems pertinent to the organization's mission. Most DoD laboratories lack this ability to move quickly into new areas, first, because most military "laboratories" are really engineering centers; second, because their charters restrict their freedom of action in any case; and third, because they lack staff and facilities comparable to those of the national laboratories. It will take fundamental changes before DoD laboratories can make greater contributions to the defense technology base. Such changes could include closing some facilities, consolidating others into weapons development centers, or converting some laboratories to GOCO facilities. This third option is considered below.[42]

Can the relations of government laboratories to their sponsor agencies be placed on a quasi-contractual basis comparable to those of GOCOs? Are any government labs considering such arrangements?

It is possible to imagine an arrangement under which government laboratories could take on the flexibility of GOCOs while remaining government-operated. For the sake of argument, a laboratory could combine the China Lake personnel system with the freedom NIST has to seek support from Federal customers, an NIF-style funding scheme, and an approach like NASA's effort to turn over its support functions to contractors—in fact, just what the DSB had in mind when it recommended that DoD sponsor a laboratory management demonstration. An organization run along those lines would have a degree of freedom that few government facilities now enjoy.

But such incremental improvements might not go nearly far enough. The China Lake system does not make government salaries more competitive with those of the private sector. Demonstration projects rarely have unambiguous results; and as China Lake shows, they tend to remain insulated from other government establishments, perhaps out of fear that their example might metastasize through the system.

Similarly, NIST's freedom to take on work for other agencies or the standards community results from its unique mission to support the U.S. technical infrastructure. And the contracting-out of support services raises legal and political issues, such as how one distinguishes between services like running a cafeteria and providing scientific computing services, which is more mission-related. In other words, when do such services impinge on governmental functions? How can one avoid the on-site supervision by government employees of contractors, which is illegal? And how can an agency avoid the inefficiency of converting base operations, function by function? In any case, such hybrid facilities would remain bound by government policies in procurement and accounting that would attenuate the freedom gained in other areas.

A single-step conversion to GOCO status could avoid these problems while bringing others in their train. However, all the GOCO institutions described earlier have enjoyed that status since their inception. If a Defense laboratory were to convert to GOCO, it would be the first instance of an existing facility taking that route. Because it would be unprecedented, a changeover would be very complex. There would be numerous issues to be resolved along the way: changeovers in employee benefits, relations with the Office of Federal Contract Compliance Programs, the need to restructure its procurement authorities, and the like. But the main issue confronting such an institution would be the nature of its relationship with its sponsoring agency. Under the new arrangement, the laboratory might be operated by an industrial contractor, a university, or even the lab's senior managers acting as a corporate body.

Alternatively, a laboratory could elect a hybrid status—contracting out all support functions, while conducting R&D as a Federal entity. A few NASA facilities, like the Johnson Space Center, have adopted such a mixed system, with all support functions turned over to a prime base support contractor. This has several advantages: for example, the contractor has direct-hire authority for

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[42] On the first two options, see ch. 7 below.

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professional staff if their work falls within the contract's scope, and it can pay them market rates. But the legal questions—the demarcation between commercial and inherently governmental functions—remain exceptionally complex.

What kind of DoD laboratory is the best candidate for conversion to GOCO? While any federally operated laboratory would benefit from fewer restrictions on operations, it seems that only a certain kind of institution is a suitable candidate for GOCO status. It should already have a substantial investment in tech base work; it should be able to demonstrate that its operating problems cannot be solved by minor variances from regulations; and its importance to its DoD customers should be such that they have a stake in improving its operations. In this light, NRL and some of the larger naval R&D centers would appear to be suitable candidates for GOCO status.[43]

A military laboratory taking this route would have problems to resolve that the DOE laboratories have never faced. One would be determining the organization for which it would be working. It might be one of the Services, a Service command, or even OSD, as is the case with some FFRDCs. Another consideration is that such a conversion could well be irreversible. Because conversion to GOCO could not easily be undone, making the transition successfully would require a strong commitment on the part of laboratory employees as well as DoD. Conversion to GOCO could not occur without the full support of the relevant Service, as well as OSD.

Finally, in return for the benefits of GOCO, the laboratories would also give up something. The new status would mean weaker ties with Defense organizations, and perhaps a tendency on DoD's part to treat the reorganized institution as simply another contractor. Further, the preceding analysis of DOE laboratories suggests that the benefits from a GOCO operation tend to diminish over time. In short, everything would depend on the sponsor's willingness to give the laboratory the freedom to strike out in new directions, and to take on work for others that drew on its capabilities. Whatever organization assumed the operation of the laboratory would have to have specialized management skills that would justify turning the lab over to an outside contractor.

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[43] On the circumstances that might justify conversion to GOCO, see ch. 7 below.

Chapter 6

Exploiting Other Management Approaches

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Chapter 6

Exploiting Other Management Approaches

OVERVIEW

As the U.S. Department of Defense (DoD) and Congress look for ways to solve problems associated with managing technology programs and research facilities, they will find that they are not alone in this concern. Other organizations—large corporations, foreign governments, and international groups—face similar challenges, and have taken a number of approaches with varying success.

For two reasons, the experiences of these other organizations warrant attention. First, they form part of the backdrop against which DoD will operate —the corporate structures and the foreign governments with which DoD will cooperate to implement its research and technology programs. Second, these organizations exemplify other approaches to accomplishing related tasks and addressing similar management problems. They offer models that might be adapted for DoD's purposes.

This chapter concentrates on organizational and management techniques, but along the way it addresses the emerging international defense-industrial environment within which DoD will operate in the next decade.

The Changing Environment

Research managers—both in government and industry—must find ways to keep up with the rapid pace of science and technology. In industry, timely applications of technology are essential to remain competitive. In the case of defense programs, the West must maintain a credible deterrent in a period of political change and uncertainty. Rapidly increasing research costs and diminishing financial resources are also causing U.S. Government officials and their industrial counterparts to rethink their research programs. The overall structure of research programs has been under scrutiny, especially the mix between long-term research and near-term applications. The use of new approaches to research and technology development—such as university-based or industrial centers of excellence—to direct interdisciplinary resources toward key research goals has grown in popularity. Policies governing intramural v. extramural research—the industrial research equivalent of make-or-buy—are being debated. On this point, the U.S. Government is unique with its large and wholly owned laboratory structure. At the opposite extreme, some governments and companies maintain no internal research capabilities at all, depending entirely on technology developed by others. Research management methods are also under review, with particular emphasis on the question of whether centralized management should replace independence at the researcher level.

Whether to collaborate or "go it alone" is becoming a major issue. In general, full-spectrum laboratories (i.e., those capable of conducting basic research, advanced development, and engineering) appear at odds with those offering specialized capabilities (e.g., centers of excellence) and focusing on selected research topics. The disparity arises because full-spectrum laboratories are often oriented along mission lines and, for reasons of efficiency or security, prefer to work alone; whereas specialized laboratories must interact with other organizations to get the job done. There is a growing attitude in governments and the private sector that collaboration, with all its inherent difficulties, is perhaps the only practical way to finance basic and applied research on contemporary topics in science and technology. Independence, whether for individual laboratories, companies, or countries, is becoming financially prohibitive, and those who insist on going it alone are increasingly at a competitive disadvantage relative to those who collaborate.

Finally, incorporating laboratory technology in products carries a high priority for companies and government officials alike. While different approaches have been taken to encourage better technology transfer, they all involve giving someone the responsibility and the authority to ensure that the process occurs. While this is simple in concept, making it happen is not easy, and few organizations do this job satisfactorily.

Other Experiences and Concepts—How Applicable?

In this chapter, approaches to technology base management employed by other Western governments[1] and by the private sector are examined to see if the successes—or failures—of others can serve as models for DoD. Japan, major European governments (those with significant military technology bases), and U.S. and European defense companies are the primary subjects. The defense sector of private industry was selected because its research methods and objectives are viewed as being more consistent with DoD's than, say, pharmaceuticals or consumer products. The specific approaches vary according to the nature of each national or industrial research program, the level of financing, and the availability of skilled researchers to do the work. In Europe, some interesting trends are developing, with governments adjusting their research programs and priorities to changes in world markets, the post-INF East-West political environment, and the advent of European economic integration in 1992.[2] A few major themes emerged from OTA's review:

- Most governments and companies have some form of "research policy," which is approved at the top and promulgated throughout the organization. While some latitude is still allowed and innovation encouraged at the research level, projects must be justified on the basis of their contribution to achieving either science and technology policy objectives or business objectives.
- There is a trend toward centralized management of research programs, with an increasing emphasis on periodic, and relatively frequent, reviews to assess actual v. planned progress. Managers appear to be more willing to cut their losses when projects continue to miss milestones, and to look outside to acquire technology developed by others.
- Private and public organizations see collaboration as a means of affording research programs that are of significant magnitude and have promise of meeting overall policy or business objectives.

It is tempting to suggest outright that DoD should embrace these themes; indeed, DoD has already begun to in some respects. However, their applicability to the Department's overall missions and responsibilities may not be entirely clearcut. Further, making sweeping changes to DoD's structure requires great caution; it may result in severe disruptions instead of the promised improvements. The magnitude and scope of DoD's technology base activities dwarf those of nearly every other organization in the world. DoD's annual Science and Technology (S&T) Program (i.e., budget categories 6.1, 6.2 and 6.3A) is approximately $10 billion, whereas the United Kingdom's (U.K.) Ministry of Defence (MoD) equivalent is less than $1 billion and, in West Germany, military S&T is just slightly more than $500 million. The U.S. Army, Navy, and Air Force each spend more on defense technology base activities than these other nations.

It may be that DoD's S&T Program is too large and diversified to employ effectively the management techniques of smaller, more manageable organizations. Nevertheless, there do appear to be methods that could be applied at least in part to DoD. This chapter highlights some promising approaches to the three broad issues that appear to be occupying the minds of U.S. Government officials and corporate executives: 1) planning and priorities; 2) management and control; and 3) getting results.

PLANNING AND PRIORITIES

Top-Down v. Bottom-Up

DoD employs a highly decentralized approach to science and technology planning. (See chapter 4.) The three Services define their research needs with only minimal direction from the Office of the Secretary of Defense (OSD), and individual researchers exert substantial influence over program content and priorities. By contrast, most other Western governments are involved directly at the highest levels in setting national research objectives—

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[1] In this chapter, "Western governments" includes Japan.

[2] The "Single European Act," passed by the European Parliament in 1985 and ratified by European Community (EC) member nations in 1986, has put in motion a set of measures that will lead to a standardized and largely integrated financial and trade system in Europe in 1992. This should, in turn, result in stronger and more competitive European industries operating in world markets.

in some cases addressing both defense and civil research with a ministry review committee. Through the use of centralized research committees or advisory panels, cabinet-level officials set priorities and take steps to ensure that the government's wishes are translated into specific programs conducted by their laboratories or by the private sector. These priorities strongly influence the content of research programs at all levels. The Japanese Government skillfully "influences" civil research activities, and the same trend is seen in several European governments. The European Community (EC) is exerting top-down influence over the scope and content of the member countries' research programs. This influence is sure to grow as the Community works toward its 1992 economic integration.

Japanese Government

The Science and Technology Agency (STA), Ministry of International Trade and Industry (MITI), and Ministry of Education constitute the three largest players in Japan's Government-directed research and development enterprise. Much of the size and influence of the Ministry of Education is attributable to its responsibility for managing educational research facilities. The other two institutions are deeply involved in planning and priorities. There exists in Japan a broad consensus on the value of research and development (R&D) efforts that provides a stable political and economic environment for the pursuit of long-term goals. Bureaucratic organizations and more politically oriented groups help ensure the preservation and continual assessment of that consensus. STA, for example, is organized under the office of the Prime Minister, while MITI's research programs report directly to the head of the ministry. Scientific research trends are monitored and influenced by advisory councils associated with the office of the Prime Minister. These councils fulfill multiple roles, including facilitating a cabinet-wide consensus on government research policies, allocating resources, and legitimizing initiatives developed in the private or public sector by publicly endorsing them. Council reports can have a considerable impact on progress in specific research fields. Space exploration, for example, has become a national priority, in part because of the role played by these advisory councils in articulating the government's objectives and gaining national support for them.

The process is not flawless. Inter-ministry integration and cooperation in Japan are not always as thorough as they could be. There have been instances in which ministries have competed against one another for prominent roles in research initiatives, forcing political compromises and wasteful duplication. And important initiatives can fail, even when there is a clear consensus in the government and industry. However, Japan's track record of successful R&D provides a strong vote of confidence for the top-down approach to planning.

British Government

Perhaps the most visible and dramatic movement away from independence and toward centralized research planning is the one now under way in the U.K. For the past 2½ years, the U.K.'s policies for R&D have been subjected to intense scrutiny by the British Government, Parliament, industry, and the scientific community. In mid-1987, the government published plans for sweeping changes in the management and funding of R&D in the U.K.[3] The proposals, which emphasized the economic potential of research, were drawn up following sharp criticism of the government's annual R&D effort by a House of Lords Select Committee.[4] The Lords had said that the government's R&D strategy lacked coordination, particularly in the way research was applied to industry. If science and technology were to restore and sustain economic growth and prosperity, the Committee said, its promotion should be a central objective of government policy, with the impetus coming from the Prime Minister.

On a related issue, a 1987 review of government-funded R&D in the U.K.[5] reported that MoD spent 52 percent of all government R&D funds in the year 1985-86. This high proportion of total R&D dedicated to defense generated widespread concern among British economists and industrialists that defense might be crowding out valuable investment in the U.K. civil sector. In its 1987 Defence White Paper,[6] the government noted this concern and promised to take a closer look at defense programs with a large R&D content to ensure that government funding was essential. Significant reductions in funding within 2 to 3 years were predicted as defense R&D became more efficient and competitive, and as Britain reduced its duplication of Allies' research efforts through greater collaboration. The aim was to release more government money to support the civil sector, both in industry and academia. In addition, there was a clear desire (both in the British Government and industry) for enhanced civil spinoffs from the R&D carried out by the government's Defence Research Establishments. Several initiatives were introduced, both to exploit the Establishments' technologies for the benefit of the civil sector, and to offer selected defense facilities for use by industry. In a potentially dramatic move, the Establishments may be combined into an independent Defense Research Agency that must "sell" its research to the Ministry of Defence, industry, and other customers (e.g., universities, European and American industries, and consortia).

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[3] "Civil Research and Development," Cmnd 185 (London: Her Majesty's Stationery Office, July 1985).

[4] "Civil Research and Development: Report of the Select Committee on Science and Technology," Vol. I (HL 20-1), British Parliament, House of Lords, November 1986.

[5] "1987 Annual Review of Government Funded R&D," Government Statistical Service, United Kingdom, 1987.

In implementing this new R&D policy, the British Government outlined two challenges: 1) to target scientific and technological resources without constraining individual creativity; and 2) to coordinate related parallel R&D programs without divorcing them from their individual objectives.[7] To support this policy there is collective ministerial consideration, under the Prime Minister's leadership, of science and technology priorities. Also, the government is to be advised by an independent body that will comment not only on British scientific and technological endeavors, but on international efforts as well. The government's stated aim is to harness Britain's total R&D resources, both civil and military, in a science and technology program that will enhance both the U.K.'s economic growth and its defense capability. The planning and execution of the more-or-less independent civil and military programs are to be coordinated and monitored by a government committee to ensure "value for money" and objectivity, to avoid duplication, and to maximize cross-fertilization between the two efforts.

French Government

In France, top-down research planning has been the rule, and appears to remain firmly entrenched. The policies for government funding of French R&D are highly centralized, but civil and defense R&D are budgeted and administered separately. Innovation and exploitation are encouraged by an elaborate system of aids and incentives; economic growth is sought through market-driven high technology; and defense R&D is expected to contribute to the overall economy. Policies for nationalized firms and the government-supported research system are framed in the context of long-term plans for R&D and innovation, with relatively specific priorities and goals. Science and technology policies (especially technology) are integrated wherever possible with the government's industrial and broader economic policies.

The stated aim of French R&D policy is to stimulate rapid, science-based economic growth, with a selection of key enabling technologies given priority in either national or collaborative programs. These goals have subsequently been reflected in legislation. The draft 1987 R&D Budget Plan was touted as an essential element in reviving the French economy. In the government's view ". . . the field of research and technological development is a fundamental component of that policy, because research and technological development are seen by everyone as being a powerful factor for the long-term development of our economies and providing a decisive advantage in present day economic competition worldwide."[8]

West German Government

West Germany presents an interesting contrast. The Federal Government's philosophy for civil research encourages independence. Bonn only promulgates general guidelines while a complex and largely informal network of Federal and State Government organizations, universities, private research groups, and industries observes priorities and moves research projects toward applications. In the MoD, however, things are different. The Bundeswehr Plan, coordinated between all three Services, forms the basis for the MoD annual budget estimate. In addition, there are two MoD agencies concerned with procurement, but not part of the military departments. The Federal Office for Military Technology and Procurement (BWB) is the principal body responsible for carrying out procurement plans. The Armaments Division is concerned with procurement planning and the coordination of technological areas that are considered "project-free" (i.e., basic research not tied to specific applications). Reporting to the Division head is the Commissioner for Defense Research, who collates the research requirements from all three Services—including international aspects—into the overall research program.

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[6] "Statement of the Defence Estimates 1987," Cm 101-I and-II (London: Her Majesty's Stationery Office, 1987).

[7] "1987 Annual Review of Government Funded R&D," op. cit., footnote 5.

[8] Draft 1987 French R&D Budget Plan.

In 1986, all responsibilities for Research and Technology (R&T) program formulation and execution were assigned to the Armaments Division. MoD has defined three categories of research: basic technology; future technology; and systems technology, which are roughly equivalent to the U.S. DoD's 6.1, 6.2, and 6.3A. These have been broken into technology elements (100 in all) with an Armaments Division Technology Coordinator assigned to each. The Coordinator prepares an annual plan that includes overall goals, a survey of the state of the art (in Germany, Europe, and worldwide) and task descriptions (with milestones and a 5-year funding profile). The Coordinator also prepares bid requests, evaluates proposals, makes awards, and monitors contracts. Roughly 25 percent of research contracts are delegated to BWB for placement. However, direct control remains in the hands of the Armaments Division Technology Coordinator.

West Germany commits about 15 percent of government-funded R&D to defense-related R&D. This is spent within the defense-related industries, the national laboratories (not owned by MoD), and the Fraunhofer Society,[9] which has six of its Institutes devoted to defense research funded by the Ministry of Defense. The defense research and technology budget is roughly DM1B (U.S.$550M) annually. For defense research the message is clear that centralized planning and control has become the rule, and that duplication cannot be tolerated. There simply is not enough money for laissez-faire.

Civil research presents quite a different picture. The West German Government's civil R&D budget is nearly seven times that of MoD. It is augmented by a nearly equal sum from State Governments, and is spent largely by universities, the national laboratories, and independent research organizations (i.e., the Max Planck and Fraunhofer Societies). Through this decentralized system, West Germany has been eminently successful in promoting technology-based economic growth, a fact that seems to call into question the wisdom of instituting a national research program based on centralized planning and control as the U.K.'s appears to be doing. Looking behind the scenes, however, German civil research is anything but laissez-faire. The Max Planck Society exerts a major influence on research priorities and the Fraunhofer Society, in conjunction with financial support from German industry, serves to "pull" the products of research out of the laboratories in accordance with identified market priorities. The "system," although not set down in formal, government-wide procedures, is apparently well orchestrated and effective, as Germany's record of industrial growth and its world leadership in exports will attest.

Private Industry

Turning to the private sector, in recent years most European and U.S. companies have instituted top-down planning systems—although specific research projects are increasingly set and executed at a division (or operating company) level. In Japan, top-down planning has always been the rule. The commitment of top management in Japanese companies to promoting technological advances within their companies is, perhaps, unparalleled. The participation of high-level managers and corporate officials varies from one firm to the next, but there is corporate-wide awareness of, and support for, research. Funding decisions frequently are made at senior levels, and failing projects are abandoned quickly, usually without their initial supporters suffering adverse consequences.

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[9] The Fraunhofer Society is a nonprofit society that sponsors and performs applied R&D. Its clients are German industry and the Federal and State Governments, and it is influential in setting the direction of German applied research. For basic research, the Max Planck Society performs a similar function.

Most major companies have elaborate procedures for establishing long-range business objectives, including an assessment of the key technologies that are expected to contribute to their achievement. For certain "enabling technologies" (i.e., those technologies with broad, corporate-wide applications), the highest management levels are involved in decisions on projects and funding. Often, corporate-level centers of excellence are established to bring a critical mass of resources to bear on the assigned tasks—a reflection of how capital-intensive research has become. These centers generally involve generic technologies (e.g., advanced materials, artificial intelligence, optoelectronics, and microelectronics), and steps are taken to ensure that the divisions use the results in applied research, design, and development programs.

To bring applied research closer to market, the responsibility for research management no longer rests solely with corporate central research laboratories; rather, the operating divisions or companies (where the profit and loss responsibility lies) are taking charge. The bulk of corporate internal R&D is thus directed toward achieving near- to mid-term business objectives, usually tied directly to identified customer requirements (e.g., DoD and MoD) or to new products. Whether this trend is good or bad with respect to industries' contribution to scientific knowledge and national technology bases, it clearly demands a firm approach, one that focuses on the bottom line and does not accept laissez-faire.

Balancing Near- and Long-Term Research

Defense Research

There is almost universal criticism that defense research programs in the United States and in Europe, both in governments and in the private sector, focus too much on the near term. This is probably a fair criticism. Engineering tasks are often conducted by DoD laboratories under the guise of technology base projects. U.S. companies direct their Independent Research and Development (IR&D) toward modernizing programs or improving current products and systems, rather than basic research.[10] And as DoD's IR&D recovery program has come under increasing pressure from both Congress and the Administration, defense companies have responded by focusing even more of their IR&D investment on those areas of technology likely to provide a near-term commercial payoff. Critics claim that the "R" in IR&D is silent. Without a government IR&D allocation, European companies are even more likely to spend R&D funds on products, rather than research.

This situation has become further entrenched in recent years as governments have reduced the percentage—and in some cases the actual level—of defense expenditures for basic and applied research. In the United States, for example, DoD's research (6.1) budget did not keep pace as defense R&D budgets increased under the Reagan Administration. In France, under Chirac, overall research was cut, with civil research taking the biggest "hit"; in the U.K., defense research is being constrained, ostensibly to prevent the crowding out of civil research. Defense research in West Germany is really too small to make a difference in the "high-tech" game.

Civilian Research

Overall, it appears that long-term civil research by European governments—and by the EC—is enjoying a resurgence, with both industry and academia benefitting from this trend. This is not an accident. Influential observers argue that **the greater the proportion of a government's research budget spent on civil research, the stronger that country will be in world markets and, therefore, the more prosperous it will become**. Japan and Germany are clear examples of this theory. Defense research is viewed as a drag on the economy, and governments are being urged not to overspend in this area. In curtailing defense research, some governments—notably the U.K.—have put the burden on industry. Companies are being urged to conduct research, either under publicly funded civil programs or with private funds, and to apply the results (in a more mature form) to defense needs.

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[10] Some observers believe that decreases in 6.2 funding could be a cause; 6.2 funding has decreased about 15 percent over the past two decades.

Japan

Japan is noted for its long-term outlook on research and technology. Both the public and private sectors adhere to this philosophy, with corporate strategies keyed to the exploitation of future technologies. This is in stark contrast to the situation in the U.S. and European defense sectors.

Several factors contribute to Japan's ability to focus on the long-term. Cultural factors are important, but there are other reasons, many of them financial. For example, in the United States the value of a company's stock influences business decisions. U.S. managers rank profits and increased share price as their primary objectives. Japanese executives also view profits and return on investment as important, but put them below market share. Further, Japanese companies do not need to worry about the price their stock commands. Equity remains less important than debt in corporate financing, and new stock issues are the exception in raising funds. Also, the lower cost of capital in Japan makes long-term projects more attractive.

A definite shift in emphasis is apparent: **While defense R&D was once the "locomotive" for advancing technology, civil research appears to be assuming this role in much of the Western world**. In part, this is because the line between civil and defense technology is fast disappearing; and in part it is because governments are moving to improve their industries' competitiveness in emerging global markets that are technology driven. In developing policies and priorities for defense research, DoD officials are sure to come under increasing pressure to take a wider view of national security. Indeed, maintaining an adequate defense industrial base may only be possible through maintaining competitive U.S. industries in world markets. The Europeans appear to have offset a near-term focus in defense with support for the long term in civil research. Their industries are finding sufficient government- (or EC-) sponsored civil research programs to challenge both existing scientific and technical staffs and available resources.

The Role of Special Initiatives

Historically, the pace of U.S. science and technology has benefitted greatly from a succession of special top-down initiatives, driven either by urgent defense priorities or by political objectives. The World War II Manhattan Project resulted not only in the atomic bomb, but also in an array of technologies that served both military and civil purposes for more than a decade. The Apollo Program of the 1960s succeeded in meeting President Kennedy's objective to put a man on the Moon; but it also provided breakthroughs in materials, electronics, data processing, guidance and control, and propulsion. Other past technological initiatives such as Project Sherwood (controlled nuclear fusion), Project Plowshare (peaceful applications of atomic weapons technology), and Vanguard (rocket development) were not successful, but they also provided beneficial spinoffs in other areas. (The Strategic Defense Initiative [SDI] program may also provide spinoffs to conventional defense programs and to some civilian fields, but the returns are not yet in.)

While these initiatives created an environment that encouraged rapid advancements in science and technology, they also disrupted the normal course of research and have, some argue, thereby undermined the Nation's long-term technological health. It is still an open question whether these initiatives have provided a net benefit to science and technology, or if S&T would be better left to follow a more natural course.

Until recently, the Europeans have made little use of special technology initiatives. Although concentrated efforts have been applied in major development programs [e.g., the Ariane spacecraft, the Tornado aircraft, the Airbus, and now the European Fighter Aircraft], national research and technology programs were relatively well-insulated from political pressures. But growing concern that Europe is falling behind the United States and, perhaps more importantly, Japan in world markets has changed this attitude dramatically. Technological initiatives are rapidly becoming the rule in Europe, rather than the exception. These initiatives have been mainly multinational in nature, directed from either the EC or other multinational groups, such as the Independent European Program Group (IEPG).[11] They also appear to have provided a "ramp effect" in several key technology areas, propelling Europe to a level of technology that is close or equal to that of the United States. While the EC research projects are for civil purposes, most involve "dual-use" technologies, and many of the results will no doubt find their way into Europe's military systems. The impact of these initiatives, therefore, will be relevant to future DoD defense technology base programs.

The EC is sponsoring several research and technology initiatives, headed by ESPRIT (European Strategic Program of Research in Information Technology). The loosely defined intergovernmental EUREKA[12] program launched by France in 1985 has attracted support from 19 European countries. After early successes—and a lot of publicity—Europe's governments encountered difficult questions on priorities and funding. The European Commission proposed a substantial research budget increase for the next 5 years. This proposal was supported by the southern-flank European countries but opposed by the major budget contributors (the U.K., France, and West Germany), who urged financial constraint and stringent selection to ensure that funded projects broke new ground. The members finally agreed in September 1987 to spend 5.2 billion ECU (U.S. $6.8 billion)[13] on a "European Framework" for technology collaboration over the next 5 years. Within the Framework are several individual initiatives addressing, for example, information technology, advanced telecommunications, biotechnology, alternative energy sources, environmental research, and nuclear safety. These initiatives have been translated into specific research programs, such as ESPRIT, RACE, and BRITE.[14] Yet, the Commission does not fund EUREKA, which could approach $5 billion in itself.

None of the more than 200 ESPRIT and 165 EUREKA projects have as yet yielded breakthroughs, although progress is claimed in many areas. The most important contribution may be psychological, with the shedding of isolationist attitudes and inhibitions. Reaction by European industry and academia to the EC programs varies from enthusiasm to open skepticism. To some Europeans, subsidized EC research collaboration administered by officials in Brussels is not a cure for Europe's problems. It might, they warn, even impede healthy change by accepting too readily the established industrial order. ESPRIT, for example, is dominated by a dozen big electronics groups. It remains to be seen if these European high-tech companies can actually cooperate in product development and marketing, thus capitalizing on the EC's investment in research.

Technological initiatives of some significance might also evolve from Europe's defense community. Driven by decreasing defense budgets, the member countries of IEPG have, after more than a decade of trying, finally begun to develop a coherent program for cooperation in research, development and acquisition. One of the IEPG's first actions was to establish a set of cooperative research projects. Little has come from this effort to date, but much more visible progress is being seen on joint development and production programs. The 1987 report of an Independent Study Team[15] signaled clearly that the IEPG would henceforth be a primary forum for collaborative defense programs within Europe, and that it would increasingly become the "single voice" on acquisition and cooperative issues involving the United States and Canada.

Centers of Excellence

Special research teams or "centers of excellence" are becoming a favored means to implement research priorities. These groups concentrate on interdisciplinary research relating to technologies that require a critical mass of resources and personnel; these are often corporate-wide activities. In the case of governments, such centers may serve military or civil interests or both at once. Some examples are described below.

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[11] The IEPG is comprised of the 13 European members of NATO: Belgium, Denmark, France, West Germany, Greece, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Turkey, and the U.K.

[12] The European Research C(K)oordinating Agency is a European program to strengthen non-military technologies, emphasizing joint industrial and government funding of civil projects that have clear market potential.

[13] European budgets for research and technology usually do not include research overhead (e.g., general facilities and administration). Also, other groups (primarily industry) are expected to contribute up to an equal share. Thus, the EC's $6.8 billion 5-year research budget is actually equivalent to a much larger amount in terms of, for example, a DoD budget.

[14] RACE: Research and Development in Advanced Communications for Europe. BRITE: Basic Research into Industry Technology for Europe.

[15] Independent European Program Group, "Towards a Stronger Europe," Vols. I and II (Belgium: NATO Headquarters, 1987).

European Community

The EC funds four laboratories, known as Joint Research Centers (JRCs), at Ispra in Italy, Karlsruhe in West Germany, Petten in the Netherlands, and Geel in Belgium. Whereas the JRCs were once the flagships of the EC's collaborative research effort, their direction, objectivity and usefulness have recently been criticized so extensively that the EC is planning to revamp their management. Under proposals adopted by the Commission of the European Community in October 1987, the JRCs are to reduce their dependence on the EC budget by 40 percent by 1991. The proposals envisaged that 15 percent of the JRCs' resources should come from contract research for individual governments and the private sector by 1991, with a larger proportion also coming from other Commission departments. While the plan does not call for cuts in the JRCs' 690 million ECU (roughly $900 million) allocation for the subsequent 5 years, the Commission proposed a sweeping reform of the JRCs' objectives, mode of operation and methods of management.

The nations, however, were unwilling to accept the Commission's proposals; West Germany called for more details on how the JRCs' performance would be monitored; the U.K. called for better control on areas where JRC work duplicates other EC research; and West Germany, the U.K. and the Netherlands thought the 40 percent reduction in dependence on the EC R&D budget by 1991 did not go far enough or fast enough. This debate suggests that the JRCs are suffering from the same malaise and lack of relevance in their research that affected many U.S. corporate research laboratories in the 1960s. In today's environment, research must be responsive to the marketplace or to military needs.

European Nations

On the national scene, the intense and public debate over the "State of Science" in the U.K. resulted in movement toward the centers of excellence concept. In late 1987, two steps were taken for reshaping British science, with emphasis on its exploitation for commercial purposes. First came the establishment of the Centre for the Exploitation of Science and Technology (CEST), based at Manchester University. Envisaged as a "think-tank" with a Steering Committee headed by the Cabinet's Chief Scientific Advisor, CEST's role is to help improve Britain's ability to exploit R&D, imported as well as home grown. CEST is to bridge the gap between industry and the scientific community; over 80 percent of its funding will come from major science-based companies and the rest from the Government.

The second step was to create a number of University Research Centres (URCs). The URCs are expected to have a vital role in the government's plan as "agents of change." Similar in concept to centers of excellence established in U.S. universities, these laboratories will be devoted to studying specific scientific opportunities that hold the promise of being exploitable within a decade. The National Committee for Superconductivity chose Cambridge University to host the first URC. The British Government's Chief Scientific Advisor is thought to believe that Britain must quickly establish 30 to 40 URCs to bring about the changes he seeks in British science.

Industry

Industries on both sides of the Atlantic have been following this trend. In Europe, nearly all major companies and universities have participated in the EC research initiatives or have joined "clubs" (consortia) striving to bring together a critical mass of resources. In the United States, major companies are also beginning to shed their go-it-alone attitudes and are seeking collaboration in key technologies, either with universities or with potential competitors. The newly formed SEMATECH, a DoD and industry consortium created to develop microelectronic manufacturing technologies, is the most recent example. Earlier examples include the Electric Power Research Institute (EPRI), the Semiconductor Research Cooperative, the Council on Chemical Research, the University Steel Resources Center, and the Microelectronics and Computer Corporation (MCC). This trend toward banding together has been encouraged by a more benign U.S. Government attitude toward the antitrust implications of joint ventures in advanced technology and by the obvious success of such ventures in Japan, and now in

Europe. While collaboration in the "precompetitive phase" of research can result in a degree of technical leveling and requires a long view of market penetration, this trend holds promise as an affordable means for U.S. industry to keep pace with international competition.

Department of Defense

In DoD, the Services, especially the Army with its University Research Initiatives Program, have been instrumental in encouraging the trend toward university centers of excellence. Such centers can and should accelerate the state of the art in technology. However, time and the danger of technical leveling could work against what should be a good idea; clearly such centers need good management. It will be important for DoD to set priorities and foster collaboration with U.S. industry, or perhaps with other governments.

MANAGEMENT AND CONTROL

Which Focus: Technologies or Missions?

Department of Defense

DoD's laboratory structure is primarily mission-oriented, with most Service laboratories dedicated to a particular warfare specialty. While some conduct (or sponsor) generic research, the vast majority are considered a dedicated asset for accomplishing one of the Service missions (e.g., Wright Aeronautical Laboratories, the Naval Ocean Systems Center, and the Army Missile Command RD&E Center). Although a mission focus provides a closer link between technology and military applications, it also encourages overlap and duplication throughout DoD. At mature R&D stages, a mission orientation may be appropriate; however, in technology base programs, where the key technologies are not yet coupled to military applications, it can be argued that DoD should be organized along more generic technology lines, with Department-wide priorities guiding individual research activities.

European Defense R&D

Recent trends within major European governments, described earlier, reinforce this argument. For France, Germany, and the U.K., defense research activities are being increasingly planned, organized, and managed by central authorities, independently of Service requirements and development activities. Research organizations are being set up to serve as sources of technology that, when mature, can feed into equipment-oriented organizations. This is also becoming the case on a multinational basis. The IEPG is considering forming a European defense research agency. On the civil side, most EC research projects are directed toward a common set of enabling technologies, with applications left to industry to determine. In the U.K., even mature research activities are being consolidated. Under a gradual rationalization policy, MoD's Defence Research Establishments have been encouraged to adopt a technology, rather than mission, orientation.[16]

Japanese Defense R&D

Japanese defense technology strategies are intertwined with an extensive process of technology management within the government and industry that emphasizes dual-use technologies to assure Japan's security in the broadest sense into the next century. To understand the direction of defense technology management, one must look beyond narrow definitions of defense and security. One must examine the roles and perceptions of a range of business and government interests in formulating and implementing technology-management policies as part of a larger economic strategy. As evidenced by the priority it places on developing dual-use technologies with multiple applications, Japan's technology policies are generated and implemented in a manner that merges economic, security, and industrial policy considerations. As a result, government and industry consciously blur the line between purely defense and civilian technologies to ensure maximum use of emerging applications and processes. They encourage a flexible approach to applying commercial technology in military systems, with the aim of making Japan equal or superior to other countries in terms of its defense technology base.

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[16] If the proposed consolidation of Defence Research Establishments occurs, the U.K.'s new Defence Research Agency may find—as has U.S. industry with its IR&D program—that research which does not directly satisfy a customer's identified needs will be difficult to justify at the "bottom line."

In Japan, there is not necessarily a national or government-wide consensus about the value of defense production and research for the overall economy. Although Japan has embarked on a policy emphasizing domestic weapons research and development, that policy is not universally embraced. The Ministry of Finance argues that virtually any spending on defense comes at the expense of the economy. This attitude is manifested in other ways. A number of major research efforts within civilian ministries and agencies have potential military applications (e.g., artificial intelligence, high-performance plastics, ceramics, advanced alloys, jet-engine research, and deep-sea mining systems). Although both the public and private sectors are examining possible military applications, the projects nevertheless are justified primarily because of their expected beneficial impact on the civilian economy.

European Civilian R&D

In Europe, the bulk of publicly funded civil research is directed toward generic technologies, especially work conducted by universities and by private research organizations. To capitalize on this investment in basic research and technology, governments are also setting up support (or technology transfer) organizations that work closely with researchers and industrialists to move basic research into useful, marketable products.

West Germany presents an interesting case where decentralization, coupled with adherence to broad national research goals, has been successful. While the Federal and State Governments have long-standing policies that nurture civil research, the researchers themselves are free to choose their subjects. This constitutionally guaranteed freedom of scientific research is the first of four basic pillars governing research policy in the Federal Republic. The second can be seen as an outgrowth of West Germany's federal structure, where the 11 federal states assume independent responsibility in the areas of education and science. The third pillar is the declared intention of the Federal and State Governments to interfere as little as possible with the research systems. The fourth pillar is symbolized by the intention that German research be integrated closely and effectively into international—specifically European—research cooperation.

The German Research Society (DFG), an autonomous organization within the scientific community, has great influence over German research programs and policies. Although DFG is funded by the Federal and State Governments [DM1 billion (approximately $750 million annually)], it is not subject to direct governmental influence. It merely shares the government's goal to seek, realize, and expand upon a high standard of achievement in basic research in West Germany. The DFG's independent staff of experts evaluates research-grant proposals submitted by researchers of all disciplines. If their decision is affirmative, approval of the grant is almost automatic. The Max Planck Society and the Fraunhofer Society, both funded largely by the Federal and State Governments, are also independent establishments that exert great influence in formulating research policies. The Max Planck Society advises on what research projects are needed at any given time, while the Fraunhofer Society serves as a catalyst for technology transfer between the scientific and business communities.

Intertwined with this, one finds German industry working both with the basic research organizations—in search of commercial "nuggets"—and with the Fraunhofer Society to smooth the way for technology transfer. Thus, while the Federal and State Governments fund basic research with few "strings" attached, **an infrastructure exists to encourage a natural evolution from basic research into product-related (or mission-specific) research which is much closer to the market**.

Industry

In the U.S. and European industrial sectors, it often appears that internally funded research is largely conducted in operating companies. Closer inspection reveals that most of this so-called research falls into the categories of development or product improvement. The really basic research continues to be conducted in central facilities that concentrate on specific areas of technology. As noted earlier, major corporations have established their own centers around key technologies, which provide a single technology source for the operating companies' use. These centers of excellence are often staffed by a combination of permanent research personnel and personnel assigned from operating divisions—the latter tasked to become skilled in the state of the art and to bring that capability into the division. Also, the trend toward banding together in research consortia further emphasizes a growing private-sector concern for technology-oriented, rather than mission-oriented, research. Both moves respond to the skyrocketing cost of research and technology.

It can be argued that multiple, mission-oriented laboratories working along parallel lines will encourage, or at least create opportunities for, greater innovation. It appears, however, that many companies and governments have concluded that the benefits of duplication are marginal and can even be detrimental if sufficient funds are not available to conduct in-depth research at multiple locations. By merging technical and financial resources, managers hope to gain the benefits of new ideas and innovation, while maintaining a central focus on selected areas of technology.

Central v. Local Program Control

In Germany and Sweden, civil research is built on a foundation of independence; the view is that independence will encourage innovation, and innovation will result in progress. An informal, but influential, infrastructure has evolved to link research to the market, with researchers having only minimal technology-transfer responsibilities. This is fine as long as there is no financial bottom line for the research establishments, or no military capabilities that are needed urgently. In such cases, one could argue that independence may not be wholly appropriate.

In Japan, government laboratories and research institutes fulfill a variety of roles in the R&D process. It is important to note that they do not serve exclusively as creators of new technologies or initiators of larger research projects. While they often serve these purposes, government facilities have an equally important role as neutral testing grounds to verify results achieved in private-sector laboratories, and to carry research to a point where it becomes more economical to pursue it in private-sector facilities. With such divisions of labor, it is not surprising that much of the interaction between business and government occurs among individual researchers, their supervisors, and the directors of research facilities.

In Japan's private sector, engineers, researchers, and other technical specialists are heavily involved in assigning priorities among potential civil research projects, and are active in the design and development phases of new products. Production and manufacturing considerations are merged with development and design stages virtually from the first consideration of a promising technology all the way through the production phase. These considerations are incorporated into product design, thus necessitating fewer costly and time-consuming modifications later. It is still difficult to determine if the same can be said for defense production in Japan, but similar attitudes and practices probably prevail.

Among Western governments and industry, there is a notable trend away from independent (i.e., "project free") defense research that reflects the need to get near-term results from shrinking budgets. An example described earlier is West Germany's consolidation of its research and technology activities under a single organization within MoD's Armaments Division. Based on priorities set at the Minister level, MoD "Technology Coordinators" develop, organize, and direct the program. These officials are expected to relate research priorities and results to future operational requirements and are often assigned temporarily to concept formulation (or pre-feasibility) study teams to ensure that research results will be used. MoD oversight of research activities is maintained at all times.

U.S. and European defense companies are increasingly holding their researchers accountable for results, especially the ultimate applications of their work to products or business objectives. As with the West German MoD, many companies temporarily assign researchers to project definition studies or long-term product development activities, emphasizing that they have a responsibility for the bottom line. The prevailing attitude in some companies seems to be that "research is too important to be left to researchers." Centralized direction, review, and feedback are the rule. While central control may tend to stifle innovation, it is becoming a financial fact of life that the industrial research community must face.

Balancing Intramural and Extramural Research

U.S. and U.K. R&D

DoD's extensive network of government-owned and government-operated R&D facilities is unique among defense establishments in the Western world. Perhaps its closest counterpart is the U.K., with its Research Establishments organized originally to support specific mission areas (e.g., the Royal Aerospace Establishment and the Admiralty Research Establishment). However, as noted earlier, these activities have been gradually consolidated and rationalized to align them more with areas of technology. Also, if the Research Establishments are separated from MoD and operated as an independent government research agency, MoD will own no research laboratories and will have to contract out all of its basic and applied research. MoD would then mirror the West German MoD, which owns virtually no laboratory facilities.

French Defense R&D

In terms of defense research, France falls somewhere between the United States and West Germany. The Ministry of Defense owns and operates, through the Delegation Generale pour l'Armement (DGA), three research laboratories (one in conjunction with West Germany). France is a special case; the head of DGA, who reports directly to the Minister of Defense, has greater control over research, engineering, and industrial matters than any other European—or American—defense official. In addition to the MoD laboratories, the French Government operates development facilities, and owns and controls a large share of the defense industry. Under these circumstances, the distinction between government and industrial research is blurred, but it seems that because of budget limitations little "project free" research is performed.

Japanese Defense R&D

Japanese intramural defense research is directed by the Technical Research and Development Institute (TRDI). Organized as a division within the Japan Defense Agency (JDA), TRDI is the Agency's primary research organization. It is headed by a civilian who oversees three administrative departments along with four uniformed directors, who supervise research and development in ground, naval, and air systems, as well as precision guided munitions. Conceptualization, design, and prototype responsibilities occur at this level. Research centers carry out projects, including surveys, research, test, and evaluation to enable further development on specific systems. TRDI maintains five research facilities in Japan for testing and evaluating a broad range of weapon systems and technologies. The Institute has no prototype manufacturing capabilities, relying instead on private-sector capacities.

The government established TRDI as an independent center for weapons development, as well as to stimulate the growth of the domestic armaments industry. It began with a philosophy of limiting direct participation in defense-related R&D, partly to minimize government budget outlays; but also because the assumption was (and still is) that defense spending constituted a burden on the civilian sector. To a large degree TRDI has managed defense technology according to its impact on the domestic economic and technological base. The Institute does not necessarily target the development of technologies to field specific weapons systems; a criterion for selecting and nurturing technologies has been the expected impact on the commercial sector. The chance that a given technology will be targeted for development by TRDI is greater if it contributes to the overall industrial base and is likely to provide commercial opportunities.

Reflecting normal practice in the Japanese commercial sector, TRDI maintains close relations between government and business. TRDI works with industry both formally and informally, in many cases simply monitoring research already under way at private companies. It also carries out preliminary research that it hands over to the private sector, once the research reaches the stage where risks have been reduced and the technology is proven. These patterns were reinforced by a reorganization in July 1987 that totally eliminated minor research programs that could be pursued more effectively by private-sector research facilities. **In addition, TRDI's role was defined to include research that lacks an immediately identifiable demand in the commercial sector.** This could mask an important change in TRDI's institutional role, and perhaps represents a JDA judgment that fielding advanced weapons systems will require selective development of specialized technologies with primarily military applications.

Civilian R&D

In European civil research, there appear to be more laboratories that are owned, operated, and supported by governments than in the United States. France maintains an extensive network of government-owned research facilities performing basic research in areas such as atomic energy, space, automation and telecommunications. These laboratories, which are staffed by researchers and administrative personnel, exert a powerful influence over French research policies. Criticisms have been voiced that these civil servants stifle innovation and serve their own purposes, rather than those of the country at large (arguments one often hears regarding U.S. Government labs). Germany, Sweden, and Italy operate a few laboratories, but rely mainly on the private sector, especially universities, to provide most research capabilities.

Industrial R&D

Despite the growing number of industrial research consortia and, in the EC, common-funded research, most industrial R&D is still performed in company-owned facilities by company researchers. This is understandable. Industry's motivations are to gain a competitive edge from research, making collaboration or contracting out risky. However, financial pressures now make research collaboration acceptable to more industrialists. Some companies have taken a different course of action by closing their central research organizations and concentrating solely on applied research. In these cases, the companies sometimes establish small advisory bodies to follow worldwide research and invest modest amounts in promising technologies, often with research institutes or universities. Such companies effectively become "technological parasites," seeking to acquire technologies from any source to apply them to products and systems to obtain a near-term effect on the bottom line.

Other companies in Europe have established hybrid programs in which some basic research is conducted in central research facilities, some in operating companies (often funded by the central research organization), and a small amount is contracted out. Rotating personnel between the research organizations and the operating companies serves to sensitize researchers and engineers to their responsibility for technology transfer. In this way, the companies hope to keep their basic research organizations as lean as possible, and yet keep ideas flowing into new products.

Through programs such as ESPRIT, BRITE, and RACE, the EC hopes to establish Europe as a major center for advanced technology, and to use this technology to establish European industries as leaders in world markets. Except for the Joint Research Centers, the EC itself has no research organizations and relies solely on external resources, e.g., industry, academe, and private research organizations. Experts are retained temporarily to help establish priorities, set research program goals, prepare bid packages, evaluate proposals, and review programs. This raises the inevitable question regarding the competence of EC staff to make informed judgments on advanced technology and to assess which technologies are ready for application. It will be interesting to follow the progress of the EC to see if an organization with such limited internal research capabilities can accomplish its ambitious goals.

Whether or not the EC succeeds, it appears that **the overall trend in Europe is toward fewer nationally owned research facilities—especially on the part of ministries of defense**. To retain technological relevance in this environment, MoDs will have to coordinate closely with national universities and independent laboratories expert in specific areas of technology. It will also require a much closer coupling between civil research and defense needs if MoDs are to maintain a state-of-the-art military force. The research must be conducted somewhere and, if it is not done in government-owned defense research establishments, then other effective mechanisms will have to be found.

GETTING RESULTS—THE "BOTTOM LINE" OF RESEARCH

Applications—Moving Technology From the Laboratory to the Marketplace

For DoD as well as for industry, the payoff from research is its application, whether to a next-generation weapon system for DoD or a successful new product for industry. If the technology is applied too hastily, manufacturing can become a nightmare and expensive redesign is often needed. Many defense acquisition horror stories are the result of attempts at concurrency—entering initial production stages before a design (or technology) is fully developed and thoroughly tested. But, paradoxically, the Department is often sharply criticized for leaving technology in the laboratory too long, thus basing new weapons and systems on yesterday's technology. U.S. industrialists are also under growing pressure because of their apparent inability to offer products that capitalize on new technology in a timely fashion and at competitive prices. **European governments and industries appear to be no better than their American counterparts at effectively transitioning new technology into weapons systems or products**. The European problem may be more the result of a lack of sufficient investment—a shortfall the EC is attempting to correct through collective investment and "transnational" research priorities. In the United States, it may be that too many technological options have been available, and that the continued promise of the "next breakthrough" frequently has paralyzed DoD's decision process.

Department of Defense

Perhaps the toughest problem faced by DoD's research managers is technology transfer—how to insert research results successfully into weapons and systems without excessive cost and before the technology becomes obsolete. Acquisition programs are essentially risk reduction programs involving a sequence of research, development, design, and engineering tasks. New technologies must pass through a number of phases during which they will be viewed differently depending on their state of development and the skills (and biases) of the personnel involved. What might be obvious advantages or shortcomings to a researcher might not be appreciated by the development engineer or designer. As a result, the technology might be used improperly or have too much expected of it, so that the insertion effort is deemed a failure. This dilemma needs to be addressed. One ambitious DoD "insertion" effort is the current very high speed integrated circuit (VHSIC) program, where existing avionics and system design programs are converting to VHSIC technology. The VHSIC program brings significant performance enhancements, but also a share of start-up problems. None of the European governments has attempted, or planned, an effort of this magnitude.

Japan

At present, Japan seems to be unique in its industry-wide ability to move advanced technology rapidly and effectively from the laboratory to the market. The current trends in Europe should be examined in light of Japanese successes, since the Europeans appear to be trying to apply Japanese concepts. What appears to work best is the establishment of teams of researchers, engineers, designers, manufacturing specialists, and even marketeers, early in the life of a technology or product. This group is responsible for ensuring the efficient movement of the technology through to manufacturing. These concepts appear to be under consideration in Europe for EUREKA and for some multinational programs sponsored by the EC, such as RACE and BRITE. Within individual European MoDs, the scope of national research may not lend itself to this life-cycle approach to technology transfer, but if research collaboration grows under the auspices of the IEPG, formal technology insertion programs may soon follow.

European Industry

Private industry in Europe is also struggling with the transition problem, as several large European companies are experimenting with new methods of managing R&D. The goal is to concentrate on the most commercially promising areas and to ensure a faster transfer of research results to the market. In pursuing this goal, R&D responsibilities are becoming more closely tied to the marketing and operating divisions—a practice that has become the rule in U.S. industry. Scientists, especially the most senior research people, are expected to support the company's business goals. They attend planning meetings and are considered part of the business team, along with the marketing and production personnel.

Examples of the close relationship that is essential between the research staff and those who develop technical specifications exist in all successful companies. However, in large and complex organizations the necessary interaction and communication can be jeopardized by interdepartmental rivalries and parochialism—problems that only strong management and a clear set of objectives can dispel. Unfortunately, examples of organizational environments conducive to effective technology transfer are few and far between, with ad hoc measures often substituting for strong management and sound policy.

A few specific approaches for assisting the flow of technology can be mentioned. Some companies recognize the need to retain continuity of technical expertise as a research project moves from research through development into production. One major European firm, with both defense and commercial operations, has developed a "distributed" technology-transfer system involving four types of laboratories:

- A basic research laboratory that concentrates on long-term topics (>10 years), working with universities and tackling problems of fundamental interest.
- Central laboratories that serve major company groupings through research on areas of common interest and on mission- or business-oriented concepts or systems (5 to 10 years before product introduction).
- Site laboratories that work on new products, funded by individual product divisions and by contracts with outside organizations (2 to 5 years before product introduction).
- Product development within product divisions, working on next-generation products, product improvement programs, etc. (1 to 2 years before product introduction).

In this company, technology transfer is effected through a "push-pull" process, with the technology moving from central to site laboratories, and from site laboratories to divisions, in a process that involves the temporary assignment of scientists and engineers to a project for 2 or more years.

In another European example, a corporate research center serving the entire company receives its funding from a variety of sources (i.e., from central headquarters, from product divisions, and from external contracts). A senior scientist within the research center monitors all research programs, relating each to possible and actual division interests. He also reviews programs for combinational possibilities, commercial leverage, etc., and arranges joint technology demonstrations for the business areas (divisions) concerned. The center has also set aside a budget to fund the business areas that will apply new technology, and routinely assigns center scientists temporarily to the business areas to effect technology transfer. While this technique works in many cases, in others it may represent too strong a "technology push," and can encounter resistance at the division level.

Some defense firms have no central research organization at all, with the divisions being solely responsible for internal R&D. While the research focus of the division is inevitably more near term to match the needs of their customers, these companies do recognize the importance of acquiring new technologies. In one example, an off-line technology group in the central headquarters maintains a "technology watch" and advises the product groups (or divisions) when key technologies approach the applications stage. The team studies research collaboration possibilities, monitors the introduction of the technology into the division's product line, carries out marketing surveys, etc. The divisions will coordinate the applied R&D on their own behalf, while the central team then moves on to its next problem.

Industry is employing a variety of approaches to encourage the efficient and timely transfer of technology—approaches ranging from secondment or temporary assignment programs to business development teams, to formal programs of "technological parasitism." The one common thread is that someone who has both the responsibility and the authority to make technology transfer work has been put in charge of the process.

Collaboration in Research and Technology

International collaboration in research is becoming a way of life for most Western nations. Not only has the cost of research become prohibitive for individual organizations, but worldwide competitive pressures in defense and civil markets are forcing companies and governments to pool their resources simply to stay in the game. These factors have triggered dramatic changes in the operating methods of high-technology organizations, including DoD. During the 1970s and early 1980s, European governments and companies and, to a lesser degree, their U.S. counterparts began to explore ways to cooperate in defense R&D and production programs. This effort spawned a number of European cooperative development projects, such as TRIGAT, Tornado and Airbus, and transatlantic programs, such as the AV-8B (Harrier), the Multiple Launch Rocket System, and the Family of Air-to-Air Weapons. However, little cooperation was achieved in intra-European or transatlantic defense research, even though cooperation was growing in civil and space research activities. In the mid-1980s, this situation began to change. Concerns about European competitiveness in advanced technology triggered initiatives by governments to promote cooperation in both defense R&D and civil research. The European members of NATO (the IEPG countries) now accept the necessity of giving up a degree of sovereignty to make more effective use of the $8 billion that they spend each year on military development, and to receive through collaboration a better value for expenditures on major procurement programs. The European members of NATO, with and without U.S. participation, have been collaborating on defense projects on an ad hoc basis for over 20 years, but the mood now is to establish a more cohesive, systematic program of collaboration in all phases of acquisition, including research.

Steps are also being taken to deregulate the entire European NATO defense industry. The 1987 IEPG Study Team issued its blueprint[17] for a common armaments market, or a military EC, which it believed could be achieved by "giving greater play to competitive market forces." By opening up fragmented and highly protected national markets, and developing a pan-European competitive and collaborative environment, the IEPG Study Team said that European NATO members should be able to reduce the costs of designing and building modern weaponry. The argument went that this would yield a more coherent European defense industry, able to **compete and collaborate on more equal terms with a U.S. defense industry that was twice its size**. IEPG ministers endorsed the report and directed their staffs to begin implementing many of the recommendations. While many hurdles remain, the deregulation of Europe's defense industry appears increasingly likely.

It is an open question whether DoD's research and technology community is ready to cooperate fully with its European counterparts. Cooperative development, with the 1985 Nunn Amendment as a catalyst, has gained favor with the Services. Important programs are now under way. For the technology base program, however, a "go-it-alone" attitude seems to prevail, with Data Exchange Agreements dominating government-to-government interactions and industrial cooperation discouraged by the exclusion of foreign firms from many exploratory and advanced technology development (6.2 and 6.3A) programs. The Nunn Amendment succeeded because it gave the Services a financial incentive to cooperate. Some type of Nunn appropriation might be needed to encourage similar collaboration in defense research and technology.

In civil research, the heightened sense of concern in Europe for its technological future is attributable to several factors, especially the scale of modern technology and recognition of the severe structural obstacles to Europe's international competitiveness. Breaking down the long-standing barriers that have isolated European companies from each other is an explicit objective of the Single European Act and the planned 1992 economic integration. The collaborative high-technology initiatives now being pursued are an important element of this strategy. European industry also sees other reasons for cooperation in research. As technologies converge, companies that once were specialists in a single activity now need to draw on a broad spectrum of sciences and technologies. Also, with shrinking product life cycles, there is a need for more frequent introductions of new ideas, thereby increasing the costs and risks of research. Companies can no longer afford to risk a generation gap in their products as the result of a research failure. U.S. industrialists also face these problems.

Other cooperative efforts have grown on a national level. The U.K. Alvey program was directed toward developing a capability in information processing that would help British industry keep pace with some aspects of Japanese and American developments. In Germany, and to a lesser extent in Sweden, a collegial relationship has developed over several decades among government, industry, and academe in civil research areas. Germany's strong position in world trade is partly a result of these relationships which, without direct government intervention, have produced an extraordinary network for exchanging information in research and encouraging product development based on the latest research results. The German system, in which a key role is played by the independent institutes (e.g., the Max Planck Society for basic research and the Fraunhofer Society for applied research), may be the best example outside of Japan of collaboration between the public and private sectors. Some argue that the German system is even better than Japan's for stimulating technology-base activities.

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[17] Independent European Program Group, op. cit., footnote 15.

Much has been said in this chapter regarding the progress of Europe's industries toward cross-border cooperation. It is certainly true that the national industries have supported their government's collaborative civil research within the EC. They have also accepted the premise that armaments cooperation (under the IEPG) has become an economic necessity. In defense research, however, there has been little industry-to-industry cooperation. This is, in part, a reflection of the meager funding available from Europe's MoDs for basic research—with government research funds being increasingly funnelled into cooperative civil projects—and, in part, a reflection of the highly competitive nature of world defense markets. While European defense companies are willing to cooperate in development programs (or at least will cooperate when their governments tell them to), their internally funded research projects, which are mainly applied research or product development, are usually well hidden from public view.

In Japan, selective cooperative research, particularly in the pre-competitive phase, plays an important role in achieving technological gains in the public and private sectors. Collaborative undertakings, though widespread, are not necessarily the rule in Japanese research efforts, and multinational research collaboration is still relatively rare. The nature, timing, and participants of united efforts vary from one field to the next. Informal and formal structures and processes tend to identify promising research fields or trends. Once a consensus has been reached between government and industry on specific avenues of research, a joint government and industry effort or a government-sanctioned research consortium (involving multiple private-sector interests) is established. As research proceeds, greater competition is introduced to hasten the introduction of products to the market.

However, Japanese companies are apparently less committed today to the consortium approach than they might have been in earlier decades. Many argue that important resources are being diverted from corporations to government-sanctioned consortium efforts without a demonstration of sufficient potential for tangible short- or long-term gains. Some firms have suggested that their own resources and decisionmaking processes are sufficient for stimulating technological advances. And, while not resenting the government role, these firms believe that it should be reduced or shifted to other forms of involvement in R&D. These same companies, however, continue to participate in deference to maintaining government relations—and out of a competitive concern that breakthroughs may be achieved by a consortium to which they would not be a party.

Despite Japanese industry's broadening disaffection with the status quo, this situation is not likely to change in the near future. In defense research and technology, for example, there are a large number of industry consortia, including those in composite materials, advanced turboprop research, and fighter aircraft. Certain projects, such as the Fighter Support Experimental (FSX), are seen literally as once-in-a-lifetime opportunities that, if neglected, could lead to the complete loss of important capabilities. Cost is another factor favoring cooperation, especially in large-scale projects originating in, but not necessarily limited to, the defense field.

Many of these same considerations affect U.S. industry as well. Although U.S. companies have recently begun to band together in the pre-competitive phases of selected technologies, they are doing so largely because of their fear of foreign competitors capturing domestic markets in which the company has a stake—not necessarily to boost the Nation's overall defense preparedness or competitiveness in world markets. Because of financial and competitive pressures, and because "1992" is making it a political necessity, one now observes a steady stream of U.S. industrialists traveling to Europe and the Far East seeking to strike deals. While most of these deals are focused on codevelopment or coproduction, American industrialists are coming to realize that Europe's technology is first-rate, and in many areas is on a par with our own. Japan's technological excellence is, of course, no surprise to U.S. executives, and the reasons for it are becoming well known. Research collaboration among U.S. companies (and with foreign companies) may become increasingly attractive if the U.S. Government provides some incentives. A two-way street in technology development might then become a reality for commercial, not just military, purposes.

Chapter 7

Implications for the Defense Technology Base: Options for Congress

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Chapter 7

Implications for the Defense Technology Base: Options for Congress

INTRODUCTION AND SUMMARY

Chapters 4, 5, and 6 of this report are an integral package. Chapter 4 addressed broad management issues facing the U.S. Department of Defense (DoD) as it seeks to plan, execute and review the defense Science and Technology (S&T) program. It highlighted the degree of control—or lack of control—exerted by the research and technology staff of the Office of the Secretary of Defense (OSD) over the priorities and content of the S&T program.

Chapter 5 examined how the S&T program operates at the "grassroots level"—the DoD laboratory. This massive and unwieldy structure presents significant management and organizational problems that DoD must solve if the defense research program is to become more relevant and productive. Chapter 6 surveyed how other sectors and other nations have tackled the problem of planning and executing S&T programs. The objective was to determine what, if anything, the Defense Department might adopt from less complex environments. The implications can be summarized as follows.

DoD's S&T program is basically a bottom-up process, with OSD serving largely in the role of monitor. While OSD's research and technology staff occasionally exerts pressure on the Services regarding specific issues, they generally yield to Service research and development (R&D) personnel on the content and direction of research programs. OSD's main role is effectively to collect the inputs from the Services, correlate them, and defend them before Congress for review. With its direct access to the Services, Congress often revises elements of a Service S&T program—with or without the agreement of the Service, and often without consulting OSD. Once the money is approved, the Services execute their own programs. The other two major S&T activities are the Defense Advanced Research Projects Agency (DARPA) and the Strategic Defense Initiative Organization (SDIO) (SDI being funded under Advanced Technology Development, budget category 6.3A). SDIO is even more independent than the Services, with the Director reporting only to the Secretary of Defense. DARPA reports to the Director, Defense Research and Engineering (DDR&E), but enjoys a degree of autonomy, on program content and priorities, from OSD's S&T monitors.

Different elements of the DoD S&T program are thus managed through three different hierarchies: for the Services, the laboratories report at a relatively low level and programmatic decisions work their way up the chain of command; DARPA reports to DDR&E, three levels removed from the Secretary; and SDIO reports to the very top. Under these circumstances, the OSD research and technology staff can do little but monitor and collect data.

This management structure also encourages duplication and a degree of inefficiency, especially considering the vast network of laboratories, centers, and other facilities responsible for research program activities. Nearly every other organization examined reflects far more centralized planning and execution of its S&T program. This is especially true in military R&D where a central authority, often reporting to the Minister of Defense (or in the case of industry, to the company president), has both the responsibility and authority to set research priorities and to ensure that the program content meets the organization's goals. With goals set from the top, there are means to exert pressure on the performing bodies to make sure that the programs are responsive. Further, at least in most governments, military research programs are generally stable over a period of several years; thus, researchers in these programs are not faced with annual—and disruptive—changes in funding or priorities. It appears that DoD is following a minority path in its conduct of S&T programs, one that is declining in popularity among governments and major companies.

Another unusual feature of DoD's S&T program is its extensive system of government-owned and government-operated laboratories. No other non-communist nation, let alone private enterprise, operates so many facilities and maintains such a large research staff. Depending on one's point of view, the DoD laboratory system is either a tremendous asset or a tremendous burden. Whether it is an asset or a burden, the structure is in place today and the Department needs to address some of the serious management and organizational problems which have beset the laboratory system.

One problem is the nature of most of the laboratories themselves. In fact, they are not laboratories; they simply lack the "critical mass" of multidisciplinary talent necessary to develop state-of-the-art technologies consistently across a spectrum of areas. Most of these organizations were created, and continue to exist, to support the mission of one of the military Services. Consequently, developing technology per se is not their primary objective. Rather, research and technology capabilities are necessary to assist a Service in performing its missions. Mission requirements can be satisfied either by conducting internal research or by contracting out to major corporations, universities, or private institutions. Each Service addresses mission support quite differently. In the Navy, a large share of the S&T budget is spent in-house. In the Air Force, the laboratories place more emphasis on becoming "smart buyers," and contract out the bulk of their S&T work. The Army falls somewhere in between. With different mission orientations leading to different approaches to R&D, overlap and other inefficiencies arise throughout the system.

A second major problem with the DoD laboratories pertains to their ability to hire and retain qualified researchers. Not only are there significant salary deficiencies, but the politicized environment in which research is conducted in many laboratories often discourages qualified scientists and engineers, sending them to higher paying and more rewarding jobs in corporate research laboratories or at universities. This situation might be mitigated if there were a DoD-wide policy to contract out as much research as possible, essentially letting the research follow the scientist. But policies regarding contracting out are inconsistent, and laboratories are sometimes forced to conduct in-house research with inadequate staff.

Finally, the government-owned and government-operated laboratories are saddled with procedures that often make them less efficient than the better industrial and university laboratories. This is an issue that must be addressed because research budgets are likely to decrease as part of an overall reduction of the defense budget. Other comparable organizations structure their laboratories differently, and some—with management problems similar to those of DoD—are currently involved in basic restructuring. One approach involves aligning research according to technology areas, creating centers of excellence that assemble sufficient resources to make a difference in high-technology fields. These centers are overseen by top management and serve as corporate-wide resources. While some observers believe that this approach stifles innovation, others argue that it increases efficiency because progress is more likely once the organization decides on the line of research it will pursue.

This assessment raises other issues. Nearly every Allied government is concerned for the future of its national research and technology programs. Politicians and the civil service agree that a country's military and economic security depend on the nation's ability to produce affordable state-of-the-art products, including weapons. Most nations also concede their inability to conduct independent research programs that are sufficiently deep in more than a few technology areas to achieve technological breakthroughs sustaining industrial competitiveness in world markets, or deterring aggressors. What money is available must be wisely spent. To ensure that this happens, European governments have set policies and priorities for research and technology at the highest governmental level—often at the level of the Prime Minister or President.

A related issue is the recognition by European governments of the "dual-use" nature of advanced technology. On one hand, government officials are painfully aware of the success of the "Japanese Model" in transferring the results of science and technology programs into quality products, thereby giving Japanese companies a competitive advantage in world markets. On the other, they see continued difficulties in exploiting technology developed under U.S./European cooperative military programs, especially from the standpoint of technology transfer to civil or to third-party military markets.

There is an international trend toward decreasing the emphasis on military technology and increasing emphasis on research for enhancing national industrial competitiveness. For example, in Europe, military research budgets are declining, while investment throughout the European Community (EC) is growing substantially. Many technologies the EC is funding have clear dual-use applications; governments seem to be expecting that the results of civil research will flow into military development and production programs. In Japan, while military research budgets are growing modestly, the government is maintaining a close connection between this research and commercial applications.

Additionally, collaboration in research is becoming important. Because most nations and private organizations find the costs of sponsoring a "world-class" research program prohibitive, they have concluded that for all its problems, banding together is the only way to go. With the emphasis on civil research and the trend toward collaboration, DoD may find increasingly that it is the "odd man out," to the possible detriment of the competitiveness of America's high-tech industries. Foreign technology in the civil fields is approaching, and in some cases exceeding, the quality of DoD's military technology. As this trend continues and the line between civil and defense research gradually disappears, it may be necessary to revise policies in such areas as international collaboration, technology transfer, foreign disclosure, and export administration.

POLICY OPTIONS FOR CONGRESS

The following policy options are based on these findings. While they are by no means exhaustive, they do address several issues that strongly affect the "health" of the U.S. defense technology base. These options take into account the interdependence of DoD's research planning and execution with events taking place throughout the S&T community, both foreign and domestic. In its consideration of these options, Congress should bear in mind that these are extremely complex matters, and that no consensus exists among experts on any of the issues or options that are presented.

The options are grouped under five broad, and unavoidably overlapping categories: 1) high-level planning, 2) organization, 3) structure of the laboratory system, 4) laboratory management, and 5) funding and budgeting.

High-Level Planning

Option 1: Establish government-wide priorities for defense research and ensure they are followed by all DoD components and the private sector.

This option addresses the need for the Federal Government to execute an increasingly complex and expensive defense research program with constrained (or decreasing) funding. The priorities could be developed in conjunction with DoD's Program and Planning Budgeting System (PPBS) process, related specifically to the early planning activities of the Joint Chiefs of Staff (JCS) and reflected in the Defense Guidance (DG). The private sector (industry and academia) could be consulted during periodic technology-assessment exercises (e.g., the planning phase of the PPBS), kept fully informed on progress and new directions (e.g., breakthroughs and political developments), and encouraged to invest in complementary research.

The methods introduced by the European Community for its joint research projects could provide some useful insights. The EC Commission sets research priorities. A 5-year budget is adopted providing for roughly 50 percent of the needed funds and industry/academia consortia are invited to submit bids. Industry funding of half the work and university involvement are necessary conditions for a bid to be considered responsive. Some factors that have contributed to success include: 1) priorities set at high political levels; 2) long-term (5-year) EC funding commitment; and 3) research work at the "precompetitive" stage, with applications left up to industry. Additionally, there is no alternative to joint research projects, because individual government funding sources are diminishing rapidly.

This model may not fit DoD's situation exactly, but it can be made to fit. The key technologies required for defense systems are largely known; and recent technology assessments, whether made by DoD or industry or both, have much in common. The Defense Science Board (DSB) could provide the connection with the private sector for periodic technology assessments. The necessary planning procedures are largely in place, i.e., the PPBS, the Joint Strategic Planning Document (JSPD) and the DG. Finally, the Independent Research and Development (IR&D) program is one source of (partial) industry funding. To implement this, a top-level commitment would be needed, with the Administration and Congress providing the political and budgetary incentives.

Option 2: Reestablish OSD's corporate oversight authority for DoD's technology base programs.

It appears that Congress has provided OSD with the necessary statutory authority to exert strong centralized guidance over DoD's technology base programs. But as chapter 4 described, OSD—specifically the Director of Defense Research and Engineering (DDR&E)—appears to have relinquished to the Services much of the responsibility for overseeing the technology base. This runs counter to trends elsewhere; as chapter 6 pointed out, our NATO Allies have initiated or further strengthened the centralized management of their defense R&D. Congress could insist that OSD, exercising its statutory authority, reestablish its corporate oversight authority for DoD's technology base programs.

OSD representatives have complained of ever-increasing congressional micromanagement of their S&T programs. Pentagon officials indicate that they believe Congress is overstepping its responsibilities in dictating how OSD should structure certain technology base programs. Some of the OSD observations may be valid; nevertheless, it is a congressional perception that OSD is not sufficiently exercising its oversight responsibilities that has led Congress into a deeper involvement in shaping DoD's technology base strategy. If OSD were to assert its authority and develop a strategic R&D plan, Congress would probably find it less necessary to involve itself in individual programs.

In various discussions with OTA, some Service representatives expressed their surprise and frustration that OSD had not exerted stronger management control over DoD's S&T programs. They contended that stronger and more effective OSD technology base oversight could go far to reduce inter-Service rivalry and produce a more coherent technology base investment strategy. However, other Service representatives argued that it would not be appropriate for OSD to exercise greater authority. In their view, because the Services ultimately would use the products of R&D programs, they alone know what is needed. Moreover, they felt that OSD personnel were too far removed from technology base programs to understand them well enough or to care enough about them to defend budgets successfully. Some argued that if Service control over technology base programs were to be reduced, the Services would lose interest in—and decrease funding for—the technology base.

Option 3: Institute a strategic planning process within DoD that will lead to a coordinated Department-wide technology base investment strategy.

Currently, the Services dominate planning for DoD's technology base program. If it wanted to provide more centralized control, Congress could consider requiring the Secretary of Defense to begin a DoD-wide technology base strategic planning process directed by the Undersecretary for Acquisition [USD(A)]. Without the endorsement of the Secretary of Defense and USD(A), it will not be possible to implement a strategic plan successfully.

Such an investment strategy could: 1) facilitate OSD-directed strategic decisions, 2) diminish the likelihood of technological surprises, 3) reduce duplication of effort, 4) encourage short- and long-term technology base planning, 5) enable OSD and the Services to examine the outputs of the S&T programs and not just the inputs, 6) enhance the understanding within DoD of the importance of technology base programs within DoD, and 7) provide Congress with a more coherent defense S&T strategy.

However, in the view of some, centralized control would only add another layer of bureaucracy between the invention of new military technologies and the managers in the Services who will ultimately have to acquire the technology for weapon systems. From this perspective, OSD staff would be too far removed from the technology base to understand the needs of the user, and protect the funding for critically important technology base programs.

USD(A) could direct DDR&E to initiate a strategic planning process that would involve the participation of the three Services, the defense agencies (including DARPA), and SDIO representatives from the JCS, the unified and specified commands, and the intelligence community. One official within the Office of the DDR&E (ODDR&E) would be responsible for developing, implementing, and directing a DoD-wide technology-base strategic plan. Developing a strategic technology base planning process would require the full-time attention of the OSD official responsible for its success.[1]

Any strategic technology base plan will have to be tied closely to DoD's national security objectives. The principal aim of the strategic plan should be to establish near- and long-term S&T objectives, leading to the achievement of the Department's operational objectives.

Once the DoD-wide strategic technology base plan is completed and approved by DDR&E and USD(A), the Services, DARPA, and the other defense agencies can use it to develop their own technology base programs. In turn, OSD can use the plan to evaluate the Services' and DARPA's technology base investment strategies and determine the extent to which each technology base program matches the plan.[2]

Finally, in view of the high turnover rate of OSD political appointees, an accepted strategic planning process should help new appointees to draft a coherent technology base investment strategy. This existing process should reduce the need for each new top-level civilian manager to "reinvent the wheel."

Organization

Option 4: Establish a central coordinating activity within the Administration to ensure that dual-use technology is exploited in the best interests of the nation as a whole.

A serious imbalance is emerging between the United States and its allies with respect to dual-use technology. Japan spends very little on defense research and technology programs; there, civil research is the main focus. This approach helps to account for Japan's enviable record of success in world trade. In Europe, the EC has committed $6.8 billion over the next 5 years to civil research, much of which also has potential military applications. The European national governments are supporting the EC and other joint civil research projects and appear to be pulling out of defense research. The U.K., for example, has limited its defense research budget so as to prevent "crowding out" of civil research—the government openly encourages domestic industry to bring the results of research to the Ministry of Defense (MoD) "when it's ready."

In such fields as high-temperature superconductivity, high-definition television, microelectronics, fiber optics, supercomputers, and telecommunications, the United States is competing with countries (or blocs) with whom we are allied in the East-West political competition. The United States, with its focus on the Soviet threat, has placed its industries at a potential disadvantage in world markets through measures such as restrictive export and technology-transfer policies. Operating under less stringent restrictions, our allies see their industries enjoying significant sales growth in market areas previously dominated by U.S. companies.

The Administration must take these trends into account as it considers the future health of America's industrial base (recognizing that the defense industrial and technology bases are only two elements of the Nation's industrial base). A balance should be found between the need to protect defense technologies (largely at the applications stages) and the growing need for industry to exploit the same (or similar) technologies in U.S. and foreign markets. Accomplishing this tricky balancing act will require the full support of the President, Congress, and industry. It will also require the appointment of a responsible and independent official with stature and authority.

This official could be located in DoD, but if so, interagency coordination (e.g., with State, Commerce, NSF, and NASA) should have high priority. Alternatively, the Office of Science and Technology Policy (OSTP) could perform this function. In conjunction with government agencies, industry and academe, broad national technology goals could evolve, with a "crosswalk" described between technology investment plans and various applications, both military and civil. Joint research projects between agencies, with industry and/or academe, or with other nations could be encouraged. Applications would be left to individual agencies; in the case of DoD this would normally be when mission needs are matched with technologies, i.e., at the advanced development (6.3A) stage. Most projects could be unclassified, with the results flowing into civil, as well as military, applications.

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[1] The President's 1983 Private Sector Survey on Cost Control, Task Force on Research and Development, indicated that it could take 3 to 5 years to implement a strategic planning process for DoD's R&D programs. Consequently, top DoD management will have to be persistent in its support if strategic planning is to be implemented.

[2] A recent Institute for Defense Analyses (IDA) task force recommended 17 technology panels to improve the coordination of DoD's S&T programs. OSD should be able to determine the extent to which each panel's activities would be linked to the strategic plan; if some S&T projects have poor linkage, they could be redirected or canceled. See "Report of the Task Force for Improved Coordination of DoD Science and Technology Programs" (Alexandria, VA: Institute for Defense Analyses, July 1988).

Option 5: Develop a coordinated, Administration-wide program of collaboration and cooperation in defense research and technology.

This option includes two kinds of action. First, better inter-Service research cooperation would be promoted, with some consolidation of responsibilities and lines of authority to improve communication and minimize duplication. The goal should be to bring to bear on key technologies sufficient resources to "make a difference." Second, a dedicated budget might be established for cooperation in research and advanced technology, involving joint research projects, technology demonstrations, and periodic high-level reviews to assess opportunities for cooperation, monitor progress, and set priorities.

Research collaboration within DoD (i.e., all three Services, DARPA, and SDIO) is widespread today, although much is ad hoc and conducted at a researcher-to-researcher level. This approach should be retained, but augmented with senior-level coordination on priorities, the assignment of lead organizations for key technologies, and a secondment program through which special skills are assembled into multidisciplinary research teams. Over time, this combination of approaches could encourage a "natural rationalization" of DoD's laboratory structure. The U.K. Research Establishments have evolved this way in the face of serious budget reductions. The Establishments were first brought under a single authority—the Controller, Establishments, Research and Nuclear (CERN)—separating them from the previous direct Service orientation. Lead Establishments were then assigned to areas of technologies with the other Establishments "encouraged" to follow. There was no need for draconian measures. Instead, a gradual rationalization occurred.

From this perspective, DoD and the U.S. defense industry need to exploit foreign technology far more than they do today. To achieve major gains, however, will require the easing of restrictions imposed on industry by strict technology-exchange and export-administration regulations as well as a reduction of time-consuming procedures that govern industrial collaboration. There is another imperative to increase cooperation on international defense research: our European allies are developing a coherent program of intra-European cooperation in civil and military research and technology. Unless the United States develops a policy for transatlantic research cooperation, we may become "locked out" of their plans. NATO armaments cooperation would suffer a severe blow, and U.S. industry might well lose existing competitive advantages in world markets.

The Nunn Amendment to the fiscal year 1986 Defense Authorization Act (and its subsequent continuation) has been a "shot in the arm" for NATO armaments cooperation. It has given both the Services and U.S. industry incentives to pursue NATO (and now non-NATO) cooperative programs in systems development. A simple extension of the Nunn legislation might provide a similar incentive for research cooperation. A specific budget (6.1/6.2), obligated for cooperative research, would undoubtedly result in increased interest on the part of Services and our Allies.

Option 6: OSD could establish DoD-wide systematic guidelines to enhance the transfer of technology into new or existing weapon systems.

Congress might recommend that DoD develop guidelines for selecting, planning, managing, and evaluating all advanced technology demonstration projects. OSD could develop these guidelines with the participation of the three Services, DARPA, and SDIO. It is important to have such guidelines, since the purpose of DoD's technology base programs is to insert new technology into weapon systems as rapidly as possible.

Because DoD's current technology-transfer process relies heavily on individual initiative, it is inconsistent and haphazard. Developing a DoD-wide advanced technology demonstration process could provide a more rational basis for setting priorities, expedite the rate at which new technologies are adopted, and provide consistent guidance for evaluating the success of various advanced technology development projects.

Option 7: Appoint a civilian research advocate in DoD with oversight of all technology base programs (6.1, 6.2), and a role in coordinating advanced technology development (6.3A) with Service research heads.

The overriding task would be to ensure that the results of DoD's technology base programs are exploited by the Services as soon as possible. Three subordinate functions are critical to this task: 1) an oversight process that augments normal "peer" review with a management review focusing on non-scientific factors, such as priority, applications, opportunity costs, and cost-benefit; 2) a means for DoD-wide dissemination of data on technologies deemed ready for transition; and 3) procedures for monitoring the efficiency of the transition (i.e., technology transfer) process.

The Administration could use parts of several models; although no single system covers all aspects of this option. In the U.K., the Chief of Defence Procurement (CDP) and in France the Delegue General pour l'Armement (DGA) have full authority over all defense R&D, and procurement. Each has a deputy for land, air, and naval systems, and a deputy for R&D, who is responsible for all "project-free" research. This approach works fairly well for these nations; however, in each case the scope of their technology base programs is less than one-tenth of DoD's—and even less is actually "project-free." It might not be appropriate to adopt these models in toto, but they do make a case for OSD to assert more authority over the content of technology base programs.

Neither the U.K. nor France has appointed a technology transition authority, and both have as much difficulty in this area as DoD. Some lessons, however, can be found in West Germany and Japan, especially in the civil fields. In West Germany, only broad civil research goals are promulgated from Bonn, and the private sector is organized to effect transfer. As previous chapters described, two influential private (but largely government-funded) societies are central: 1) the Max-Planck Society performs basic research and serves as a "locomotive" for other research institutes and universities, and 2) the Fraunhofer Society performs applied research and couples closely with industry to effect technology transfer into the marketplace. While not effecting direct control, a number of government-sponsored groups provide oversight and advice. In Japanese industry, teams are formed at early stages of research that consist of researchers and experts from engineering, design, manufacturing, and marketing. Their basic mission is to ensure the fastest practical transition from research to a marketable product.

DoD is well positioned to adopt this option. The Goldwater-Nichols DoD Reorganization Act established the USD(A) to oversee all defense R&D and acquisition. The DDR&E, reporting to USD(A), looks across all of DoD's technology base programs. DARPA's new role in prototyping, and its recently expanded involvement with technological initiatives, provide the framework for a "transitioning" authority. However, budgeting and review authority over most of the technology base program rests with the Services and other DoD components. Congress and the Administration could bring these elements together under DDR&E and charge this senior official with exploiting the results of the government's $10 billion annual investment in research and technology. However, this could result in greater technology push, which some believe could be detrimental to U.S. defense efforts.

Option 8: Streamline the current OSD organizational structure for RDT&E programs.

Peter F. Drucker has discussed the importance of sound organizational structure:

> Few managers seem to recognize that the right organization structure is not performance itself, but rather a prerequisite of performance. The wrong structure is indeed a guarantee of nonperformance; it produces friction and frustration, puts the spotlight on the wrong issues, and makes mountains out of trivia.[3]

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[3] U.S. Senate, "Defense Organization: The Need for Change," Staff Report to the Senate Committee on Armed Services, Oct. 16, 1985, p. 92.

The current DoD organizational structure for research, development, test, and evaluation (RDT&E) appears ill-suited to its role. Both civilian and military representatives have argued that if DoD's technology base programs are primarily responsible for maintaining DoD's scientific and technological superiority, then the official in charge of the RDT&E program should report directly to the Secretary of Defense. The Goldwater-Nichols Act puts primary responsibility for the technology base program with the DDR&E, who reports to the USD(A). Unfortunately, DoD's general preoccupation with procurement issues has diverted the attention of the USD(A) from important technology base issues.

Within ODDR&E, the Deputy for Research and Advanced Technology (R&AT) is responsible for oversight of the Services' S&T programs, while the Director of DARPA reports directly to the DDR&E. This organizational arrangement has made it difficult to coordinate DARPA's activities with those of the Services fully. Although DARPA's mission is different from the Services', its ultimate responsibility is to support the development of high-risk technology for the Services. This activity could be facilitated by requiring DARPA and the Services to report to the same office.

Finally, any organizational review focusing on the technology base should include SDIO. Since the Director of SDIO reports to the Secretary of Defense, there is no formal technology base coordination with the Services and DARPA. If OSD is to develop an effective technology base investment strategy, much closer coordination will be needed between SDIO, DARPA, and OSD.

Option 9: Improve DoD's ability to attract top-quality political appointees and high-level civil servants.

Current and former DoD S&T personnel assert that DoD is unable to attract individuals of high scientific and managerial talent. They contend that this problem must be solved if competent civilian leadership is to be restored within OSD and the Services.

There appear to be three specific actions that Congress could take to help resolve this problem:

1. increase salaries of DoD science and engineering personnel,
2. amend the conflict-of-interest statutes, and
3. amend the Federal tax laws with respect to the forced divestiture of assets.

These recommendations are not new, but are presented as options to highlight a problem that appears to be deepening.

Numerous studies conducted by the Federal Government and the private sector have documented the growing disparity between compensation for top Federal S&T personnel and that of their university and private-sector counterparts. Congress could examine the possibility of eliminating pay caps for senior executives within DoD and instituting compensation that reflects the current market for such individuals.

DoD should also have a pay structure that compensates officials on the basis of their S&T management responsibilities. Unlike the private sector, the Federal pay cap fails to distinguish between a laboratory director who manages the activities of 3,500 people versus a director who oversees a 500-person laboratory—or for that matter an OSD Senior Executive Service (SES) manager responsible for supervising a 12-person staff. DoD cannot pay top scientists and engineers what the private sector can.

Past and current DoD civilian personnel assert that potential top-level political appointees—and scientists and engineers—are often reluctant to make the financial sacrifices required under the Federal conflict of interest or "revolving door" statues in order to accept a high-level DoD position. As the Senate Armed Services Committee study on the DoD organization observed, rather than altering the divestiture requirement, Congress could alter Federal tax law with respect to the forced sale of assets.[4] This would still protect the objective of maintaining public confidence in OSD officials, but it would reduce the onerous financial consequences of accepting public service.

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[4] Ibid.

Structure of the Laboratory System

Option 10: Restructure the military's RDT&E organization by establishing corporate laboratories for each of the military services and creating some full-spectrum weapons development centers.

The creation of "corporate" laboratories dedicated to individual Services would rationalize the conduct of DoD's RDT&E program. Corporate laboratories could perform the bulk of each Service's technology base work, by generating research concepts and bringing them to the demonstration phase. The laboratories' mission would be to marshal the technical resources of their Services to attack new objectives. This would require DoD to increase its investment in technology base programs, rather than have the corporate laboratories compete with academe for a shrinking 6.1 budget.

The existing engineering and development centers would have to continue to establish priorities in their development programs, pursue a dialogue with the corporate laboratories, and position themselves to transition technology. At their discretion, they would also compete for that portion of the corporate laboratory's funds that would sponsor external technology base work.

The creation of corporate laboratories would involve more than establishing the equivalent of the Naval Research Laboratory for the Army and Air Force. Corporate laboratories could receive funding from a variety of sources, under procedures analogous to those by which the Department of Energy (DOE) national laboratories—and even some of DoD's federally funded R&D Centers—receive their funds. They would receive multiyear block funds to cover the programs authorized by their respective Service, plus reimbursable funds to support work for others. In this context, "others" would include the other military Services, independent Defense agencies like DARPA and SDIO, and civilian Federal agencies.

The Services might create semiautonomous units within their corporate laboratories for certain kinds of high-risk, high-payoff programs. A Service might consider a particular discipline or mission area so important that it would justify the creation of specialized units working on them. The Army has used this approach in setting up its Night Vision and Electro-optical Laboratory and the Life-cycle Software Engineering Center. Even research in highly specialized areas requires collaboration by experts in several disciplines. And if the work is well done, the results of such specialized research can flow into other areas.

Corporate laboratories could create a much richer network of external relationships—comparable to those enjoyed by DOE's national laboratories. The laboratories' work in basic research and exploratory development could make them more attractive partners for collaborative ventures. These relationships could include: technology transfer mandated by the Stevenson-Wydler Act; work for non-Federal sponsors like that done by the National Institute of Standards and Technology (NIST); and the building of formal and informal communication networks with universities and industry. Far from precluding collaborative work, the corporate laboratories' missions would virtually require it. The point is to avoid the two extremes: laboratories serving as "pass-throughs" for development money, on the one hand, and on the other, the inbreeding that results when laboratories try to do everything in-house.

Congress and DoD might also create weapons development centers to pursue work on significant military systems problems, as was suggested in a 1966 Defense Science Board (DSB) report.[5] While private industry would continue to do virtually all of the engineering and production work, these centers would encompass the full spectrum of activities from advanced development (6.3B) to the creation of feasibility models to demonstrate "proof-of-principle" in a military environment. These centers would be project-oriented research and engineering institutions working in broadly conceived weapons areas.

As the DSB defined it, weapons development centers would have certain family resemblances. They would have a critical mass of at least 1,000 scientists and engineers; the center director would have direct control over all the necessary resources;

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[5] Defense Science Board, "Department of Defense In-House Laboratories," report prepared for the Office of the Director of Defense Research & Engineering, Oct. 31, 1966, p. 9.

center specialists would participate in determining military requirements associated with its mission; and the center would be involved in the initial procurement of equipment. Instead of serving as pass-through agencies, each center would do most of its development engineering in-house, with contracts serving to support such work.

The advantages of this approach are straightforward. A weapons development center would have the critical mass to work on a range of problems, clear responsibility for its end products, and the ability to respond quickly to military emergencies. The existence of such centers would enable DoD engineers to work on military problems and to bring together specialists in many disciplines.

In creating such centers, certain problems would have to be solved; for example, how would a center concentrating on aeronautical development relate to one whose mission encompassed missile design? Further, each center would inevitably be biased toward its own system, even if another kind of weapon or platform would provide a better military solution. As the DSB panelists were well aware, by their nature such centers would tend to commit themselves to long-term projects, even in the face of evidence that other approaches might work better. Such centers could easily reduce their contractors to suppliers of narrowly specified equipment and services, with nothing to offer to the center's portfolio of ideas.

Option 11: Consolidate some military laboratories and close others.

A case can be made that there are too many DoD facilities whose contribution to the defense technology base is difficult to discern. In the current environment, both Congress and DoD should explore merging some facilities that can no longer stand on their own and closing others. This option appears radical only if one assumes that Federal facilities are permanent. There is no definite Federal policy on the closure of government facilities, although something can be gleaned from Office of Management and Budget (OMB) circulars barring agencies from performing activities more suitable for the private sector. Agency officials have asserted principles that might justify closing a substandard laboratory: if it has served its initial purpose, if there is no likelihood that a new role for the laboratory can be found, or if closing the laboratory would not leave a significant gap in the national capability to perform R&D.[6]

Consolidation and closure may be more palatable options now than at any time since the mid-1970s. The closing or merging of R&D facilities has not always been unthinkable. In the early 1970s, for instance, the Air Force undertook a major reorganization of its laboratories, converting its Cambridge Research Laboratories from a basic research to an "exploratory development" institution, closing the Aerospace Research Laboratory at Wright-Patterson AFB, and delisting one of its contract research centers. This was also the period when NASA closed its Electronics Research Center and transferred the facility to the Department of Transportation; and when part of the Army's Fort Detrick became a contractor-operated facility working for the National Institutes of Health.[7]

The present budgetary environment will probably encourage the Services to make difficult but necessary choices. Short of actual closure, the Services could employ a number of strategies to keep the weaker laboratories going—authorizing them to seek support from other sponsors, clarifying their roles, and redirecting them. But at some point, the Services may decide that they can no longer carry all of the research centers they currently support. For a Service, there may well be a bigger payoff in cutting, say, 20 percent of its laboratories than in slicing 20 percent from each laboratory's budget.

The advantages of this approach are threefold: first, fewer laboratories would make the remaining ones more visible to their sponsors; second, more funding available to the remaining centers would strengthen them and probably produce more worthwhile research; and third, closing some laboratories is a necessary step to consolidating disciplines that should go together.

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[6] Arnold S. Levine, *Managing NASA in the Apollo Era* (Washington, DC: National Aeronautics and Space Administration, Scientific and Technical Information Branch, 1982), p. 137.

[7] For these and other examples, see T.J. Wilbanks, "Domestic Models for National Laboratory Utilization," in Energy Research Advisory Board, *The Department of Energy Multiprogram Laboratories, Volume II: Special Studies* (Oak Ridge, TN: Oak Ridge National Laboratory, September 1982), pp. 66-67.

DoD could possibly strengthen its technology base with fewer and larger laboratories and engineering centers, because they would have the critical mass of professional staff to move on several research fronts. On the other hand, the question of which facilities to merge or close is exceedingly complex and highly political, and changes would require several years to implement.[8] A useful precedent for an approach might be found in the recent base closure legislation. Adopting a similar "package deal" might ease the process.

Option 12: Promote the sharing of "national" facilities and the interchange of personnel between government laboratories.

In the current budgetary environment, few agencies have the luxury of duplicating existing facilities. The sheer expense of building a new wind tunnel or particle accelerator is forcing agencies to turn to collaborative ventures—a tendency that should be encouraged. At the same time, no agency will willingly depend on another to accomplish some of its most important programs. The creation of national facilities available to all qualified users is one way out of this impasse.

The multiprogram DOE laboratories are not the only "national" entities that the government sponsors. Since 1980, NASA has opened two national facilities at its research centers: the National Transonic Facility at Langley Research Center, and the Numerical Aerodynamic Simulator at the Ames Research Center. Both are world-class facilities that keep the United States in the forefront of aeronautical research and serve all U.S. commercial, military, and scientific requirements.

The creation of such national facilities bears on the DoD laboratories in several ways. First, and most obviously, they would obviate the need for DoD to duplicate—at great expense—facilities that already exist. Second, as resources available to all qualified users, they actually make the military laboratories more productive, with no investment beyond that required for covering their share of facility operations. And third, the NASA facilities offer the options of either onsite use of facilities or remote access, via data communications networks that are now in place.

The same principle of shared use applies to NIST and the multiprogram DOE laboratories. The mission of NIST demands extensive work for other agencies in a variety of areas. At the same time, the DOE weapons laboratories are seeking a broader defense role in nonnuclear weapons research. Given their capabilities, one might expect that the DOE laboratories' multidisciplinary strengths could become a major resource for DoD.

Program and budget pressures will no doubt force DoD laboratories to work more closely with each other and with those of other agencies. Congress could explore the possibility of giving corporate laboratories created by each Service the freedom to take on the work of others. Like the DOE laboratories, a certain portion of each laboratory's operating budget would include work undertaken for another Service, another Federal agency, or even State and local governments. By working for others, laboratory scientists and engineers would acquire more of a "hands-on" acquaintance with dual-use technologies than an individual Service might be able to fund. A broader base of interests would, in turn, allow researchers from all the Services to work on many generic technologies (e.g., software engineering, weapons simulation, and high-speed processing) that could lead to Service applications.

It might also be to the DoD laboratories' advantage to promote an exchange of personnel with other facilities working in similar areas. There are precedents for such assignments. For many years, NIST has had a Research Associates program, whereby scientists and engineers from industry can come to NIST at their company's expense to work for a specified period on projects of mutual interest. The DOE laboratories have had even closer ties with outside organizations, not least because their contractor status virtually demanded it. These arrangements include joint ventures with industry, summer study programs, joint appointments with the operating contractor, and the creation of university consortia like Oak Ridge Associated Universities.

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[8] Another option, not further considered here, would be to keep certain laboratories in the "doubtful" category open, while leaving them free to seek support from any sponsor willing to provide it. A military Service would not be responsible for assuring a total level of support. Instead, the lab would be placed on a footing analogous to Naval Industrial Funding, with military and other customers paying for much of the cost of operations.

A program to promote short-term exchanges of laboratory personnel would serve DoD aims in many ways. It would give DoD scientists and engineers a better idea of the research being sponsored at DoD and other government laboratories. It would enable professionals from different services to work on generic, or cross-cutting, technologies. Finally, it would promote the idea that DoD laboratories—particularly the corporate institutions—are resources that should be freely available to all of DoD, as well as some of its industrial contractors.

Laboratory Management

Option 13: Convert some government laboratories to government-owned, contractor-operated (GOCO) status.

From time to time, government panels like the White House Science Council and DSB have suggested that some government-operated labs should convert to GOCO status. Experience in such conversion is limited to the partial 1983 conversion of a small DOE technology center to private operation.[9] All other GOCO laboratories have had this status since their inception. The issue that DoD and the Congress should consider is what, if any, advantages would flow from a GOCO conversion that could be achieved in no other way. It is significant that, in its 1987 summer study, the DSB proposed such a conversion for existing laboratories mainly as an alternative to improving their operation within the system. As the study group put it, "where existing government laboratories are not performing well, conversion to a GOCO laboratory has some attractive properties." But it also added that "such conversion would involve significant disruption and political opposition."[10]

Based on the DOE's experience, the Federal R&D community knows something of the advantages and disadvantages of the GOCO approach. The greatest of these advantages is flexibility in personnel management: flexibility in developing personnel systems; flexibility to set salaries at levels comparable to those in the private sector; and flexibility to move staff from one activity to another on short notice.[11] And provided they comply with Federal norms, GOCOs face a somewhat lighter regulatory burden than do their government counterparts.

GOCO arrangements also carry disadvantages. Some analysts claim that GOCO status reduces a laboratory's commitment to its sponsor's mission, and that there may be a perceived conflict of interest if the contractor is a for-profit corporation. Other, more fundamental criticisms are that the system fosters a lack of accountability and that, by turning technology development over to a contractor, the government loses control of the operations of its laboratories. Nor are GOCOs free from the more burdensome kinds of oversight. If anything, these institutions tend to impose on themselves the kinds of burdens from which their status as GOCOs supposedly exempts them.

In sum, GOCO status may be an option under carefully specified conditions: if an agency is considering a new facility; if government operation forecloses the possibility of improving a laboratory's operations; or if the sponsoring agency wants the expertise of an industrial contractor for production facilities or of a university for research and development. At this time, there may not be enough hard evidence either way to justify the conversion of a government laboratory to GOCO status.

Option 14: Eliminate institutional barriers to the effective operation of DoD laboratories.

Congress could facilitate change by extending practices at certain facilities to the rest of DoD's R&D community. The measures discussed below are in line with the DSB's 1987 recommendation that each Service select at least one "representative" laboratory, and so alter its management that it could attract the highest quality staff, improve operations, and provide management with "authority and accountability."[12]

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[9] In 1983, the Energy Department transferred responsibility for its Bartlesville Energy Technology Center to the Illinois Institute of Technology Research Institute (IITRI). Under a cooperative agreement between DOE and IITRI, the center, renamed the National Institute for Petroleum and Energy Research, would work for both government and industry. IITRI is responsible for the facility and shares operating costs, but receives no fee. The contract provides that fees earned from industrial clients revert to DOE, and that for basic research, IITRI must write an annual work plan for DOE approval.

[10] Defense Science Board, "Summer Study on Technology Base Management: How to Improve the Effectiveness and Efficiency of the R&D Process," report prepared for the Office of the Under Secretary of Defense for Acquisition, December 1987, p. 15.

[11] On these and other GOCO features, see Office of Science and Technology Policy, Executive Office of the President, "Final Report of the Working Group on Federal Laboratory Personnel Issues," July 1984, p. 24.

The most immediately obvious changes would be in personnel management. For example, Congress could extend the approach embodied in the China Lake experiment (described in ch. 5) to all DoD laboratories. This would give technical directors and their division managers added flexibility to recruit and promote effectively: broad pay bands that incorporate a simplified classification scheme; an employee appraisal system that links pay to performance; and an emphasis on performance as a primary criterion for retention. If anything, the China Lake approach could be more carefully tailored to the problems of professionals working at government laboratories. DoD might combine features of both the China Lake and NIST demonstration projects: the consolidation of 15 grades into a few broad pay bands and the delegation of classification authority to line managers that is common to both projects; and NIST's direct-hire authority and the ability to offer its professional employees total compensation "comparable" to that offered in the private sector for the same positions. In addition, Congress might consider allowing laboratories to pay exceptional scientific and engineering talent market rates above civil service ceilings, and pay competitive salaries for all technical employees.

This option raises two opposing questions. Why should an approach tried at three facilities be extended to the rest of DoD? Conversely, if the China Lake/NIST approach has been successful, why not extend it government-wide? China Lake demonstrated that a simplified personnel system could raise employee morale and lead to higher retention of more capable professionals, even if it did not automatically lead to government pay scales that were more competitive with the private sector. In answer to the question, "Why not government-wide?" it can be argued that the current DoD (and central oversight agency) approach to personnel and financial management violates a basic rule of equity: Do not treat unlike institutions as though they were alike. A scientist at the Air Force Wright Aeronautical Laboratories should not be covered in quite the same way as a Treasury official who maintains the government's central accounting system or a General Services Administration official who manages public buildings. The merit of the China Lake and NIST approaches is precisely that they recognize that different groups deserve to be treated differently.

The China Lake experiment may give technical directors and division chiefs an irreducible minimum of authority in hiring, promoting, and firing. Similarly, a laboratory technical director should have direct authority over all of his organization's functional offices, such as personnel, procurement, and data processing. Lacking such authority, no technical director can be fully responsible for his laboratory's operations.

Congress should also consider reforming the ways by which the laboratories receive and spend their operating funds. Studies have shown the effects of overmanaging and underfunding DoD laboratories. In particular, laboratory officials have to cope with uncertain funding—so uncertain that funds often do not reach them until late in the fiscal year.

Multiyear and no-year funding might give DoD laboratories the same kind of institutional stability that the DOE's national laboratories enjoy. Especially where technology base work is involved, technical directors need the assurance that work will be both fully and continuously funded, that funds will cover all expenses, and that funding will be assured over the life of a project. Block funding could very well provide this assurance. Under this approach, a laboratory would receive a lump sum sufficient to cover the full costs of technology base work, without the need for allocating funds under existing DoD budget categories.

Laboratory directors also need discretionary funding to start new work, to sustain projects where other funding is incapable of carrying them to completion, and to encourage cooperative ventures between the laboratory, universities, industry and other Federal agencies. The 1983 Packard Report recommended that between 5 and 10 percent of a laboratory's annual budget be reserved for independent R&D at the director's discretion—a range that would permit potentially important work that now goes unfunded.[13] While officials will disagree on the appropriate size of the discretionary pot, this much must be said: if a Service considers a laboratory's mission worth doing at all, it should accord a certain percentage of discretionary funds as a matter of right.

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[12] Defense Science Board, op. cit., footnote 10, p. 19.

The acquisition process is another area ripe for reform. Evidence mounts that the length and complexity of acquisition cycles impose tremendous paperwork burdens on military laboratories. Congress is aware of these problems, and has put in place mechanisms that have somewhat eased the laboratories' burdens. These include the use of Broad Agency Announcements for research and exploratory development, the exemption of certain kinds of scientific computers from the "full and open competition" provisions of the Competition in Contracting Act, and the use of a simplified procedure for Small Business Innovative Research (SBIR) procurements. These approaches could be extended to other operations, for example, the acquisition of office equipment and general-purpose computers.

A major reform in acquisition must reflect a proper sense of the laboratories' missions. A laboratory, most of whose personnel monitor contracts, cannot easily carry on its inherently governmental functions, act as a smart buyer, and serve as a center of technical excellence. And yet the majority of military laboratories are conduits through which buying commands funnel money to industrial contractors. Instead of the laboratories acting as pass-throughs for development work, it may be that such procurements could be handled directly by the Service commands, with the laboratories providing supporting research before a buy occurs and technical consultation afterwards.

Option 15: Allow DoD laboratories to contract for those services that are not inherently governmental.

As an alternative to GOCO conversion, DoD laboratories might elect to contract for those services that are not essential to the conduct of R&D. The principal guidance on acquiring commercial products and services needed by the government is contained in OMB Circular A-76. Although that Circular specifically exempts R&D work from its coverage, it does include "severable" commercial activities in support of research and technology development. Given the blurring of lines between, say, scientific programming and the work of in-house researchers in artificial intelligence, it is often difficult to distinguish between activities that are and are not covered by A-76.

The important issues, though, concern efficiency more than policy. A facility that contracted out all support services would achieve a status somewhere between government operation and GOCO. Such contracting out would serve several purposes. It would enable laboratories to pay market rates for support services; give laboratory executives greater flexibility in hiring workers and dismissing them when they were no longer needed; and bring in professionals who would not work directly for the government. Under such a system, a laboratory could, for example, contract out facility management, supply operations, and financial and administrative processing. Scientific and engineering professionals would remain government employees, either under a reformed personnel system based on the China Lake model or some special system, like the one used to pay faculty of the Uniformed Services University of the Health Sciences.

The best example of this hybrid system can be found in the NASA centers. Since its establishment in 1958, NASA has routinely contracted out almost 90 percent of its total budget, with much of that going for center operations. NASA sponsors two kinds of contract support. First, an agency installation may be managed by government employees, with NASA awarding a master contract for housekeeping and base support and separate contracts for more specialized functions. This is the arrangement at the Kennedy Space Center, where EG&G provides base support, and at the Johnson Space Center, where Rockwell International is the prime contractor for mission support. Second, a NASA installation may be government-run, but without a master support contract. Instead, the center would let separate contracts for services such as technical writing, janitorial services, image processing, computer programming, or the operation of tracking stations.

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[13] Executive Office of the President, "Report of the White House Science Council, Federal Laboratory Review Panel," Office of Science and Technology Policy, May 1983, p. 8.

It is important to determine if a hybrid system along these lines could work at DoD. The advantages listed above seem clear enough. The disadvantages are not nearly so. Nevertheless, the bifurcation of support and essential functions might be difficult for a laboratory to sustain over the long run. Further, there are legal questions relating to the supervision of contract employees by government officials. It is the Office of Personnel Management's position that such supervision constitutes a personal service contract and is illegal. It could be argued, though, that so long as the sponsoring agency simply lays down a general requirement—for example, "We need someone to run this facility"—it could remove such contracts from the prohibited category. So long as a few military laboratories are candidates for GOCO status, the hybrid arrangement could be an attractive alternative—provided the legal and other uncertainties surrounding it are removed.

Funding and Budgeting

Option 16: Institute multiyear budgeting for DoD's RDT&E program.

DoD first submitted to Congress a 2-year RDT&E budget request for fiscal year 1988 and 1989. Congress approved a 2-year authorization, but appropriated no funds for the second year. Congress might consider reviewing the feasibility of providing multiyear appropriations for DoD's technology base program.[14]

Multiyear appropriations should decrease the amount of time OSD personnel spend preparing, reviewing, and defending annual budgets. It would also add stability and efficiency to technology base activities by providing known funding levels for future S&T programs. By reducing the number of programs that have to be acted on in any one year it could also provide Congress with time for more thorough oversight activities, such as giving the Appropriations Committees more time to study the recommendations of the authorizing committees.

Certainly, there are some disadvantages to multiyear funding. Congress would be giving up some of its annual oversight powers. Further, if budget projections proved to be inaccurate it could be difficult to make mid-cycle revisions, or to accommodate changes in budget priorities. Yet, multiyear budgeting could give OSD and Congress additional time to consider technology base activities in terms of strategic options. Combined with a strategic technology base plan, a multiyear budget could improve the ways in which Congress reviews DoD's technology base programs. Lacking a coherent technology base strategy, OSD now presents its S&T budget to Congress primarily as the sum of individual program elements. An overall strategic budgeting approach would help Congress understand the trade-offs and implications of different technology base funding options.

Finally, multiyear appropriations could facilitate DoD's ambitious goals for allied R&D cooperation. By 1994, 10 percent of DoD's RDT&E budget is to be committed to joint R&D projects with NATO and other allies. Many Pentagon officials believe that this goal is not attainable under the present annual budgeting cycle. They argue that the European Allies earmark funds for 3 to 5 years for R&D programs, and that European officials may be reluctant to enter into numerous high-risk, cooperative R&D programs with the United States unless Congress is willing to guarantee funding for more than one year.

Option 17: Separate the technology base budget from the development, test, and evaluation portion of the RDT&E budget.

Although the ultimate success of many development programs may depend on underlying technology base projects, the 6.1-6.3A portion of DoD's budget is often overlooked in the "high-stakes" game of RDT&E budgeting. The Pentagon's top-level budget review committee, the Defense Resources Board (DRB), seldom considers individual technology base programs or priorities; rather, it usually addresses only broad issues of spending level.

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[14] In this case, multiyear appropriations could mean a congressional funding commitment of from 3 to 5 years, with Congress reserving the right to review the program at the conclusion of its second or third year of funding. Roughly half the Federal budget is permanently appropriated. (A permanent appropriation is budget authority that became available as a result of previously enacted legislation and does not require annual action by Congress.)

USD(A) could provide Congress with an RDT&E report that clearly highlights the achievements of the Department's research, exploratory development, and advanced technology development programs. The report could summarize current and future major thrusts of the technology base program, demonstrating the linkage between these activities and future military capabilities. It would also be useful if the report were to address potential civil applications of selected technology projects, in recognition of the increasingly dual-use nature of advanced technology.

The funding portion of the report should clearly separate technology base funding trends from the remaining "DT&E" portion of the budget. This breakdown could provide Congress with a clear picture of DoD's RDT&E funding priorities—and thus the "health" of the defense technology base. For example, if the report were produced today it would reveal that research (6.1) and exploratory development (6.2) programs have suffered significant declines in recent years. If Congress wished to do so, it could instruct USD(A) to halt this funding decline.

Chapter 8

Lab to Field: Why So Long?

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Chapter 8

Lab to Field: Why So Long?

INTRODUCTION

This nation's military strategy depends upon maintaining a technological lead in fielded military weapons systems, both to take advantage of the strong U.S. technological capability and to compensate for a numerical disadvantage relative to the Soviet Union in many categories of weapons. Nevertheless, leading defense officials are concerned that the technological level of operational U.S. weapon systems lags considerably behind the state of the art.

Some of this discrepancy is unavoidable. Many systems now in the field have been there a long time. Those just now entering service had their designs substantially frozen years ago, while the level of technology in the laboratory has continued to advance.

The inherent time lag between lab and field notwithstanding, the length of time it takes for new technology to be fielded in U.S. military systems is disturbing. According to the Department of Defense (DoD),

> The Soviets are methodically and efficiently transitioning new technologies into their vast arsenal, oftentimes more rapidly than the West . . . Consequently, the Soviets, although lagging the West in technology, frequently field systems that are sufficiently well-engineered to meet or exceed the capabilities of counterpart Western systems.[1]

A 1987 study by the Defense Science Board (DSB)—a panel advising the Secretary of Defense on technical matters—found that the inability to move technology rapidly from research and development (R&D) programs to systems and products "is a primary contributor to the growing crisis in military competition as Soviet weapons system performance approaches and, in some cases exceeds, that of U.S. and Allied forces."[2]

Figure 4 shows when several technologies now in use in Air Force systems first started to be developed in the laboratory. Some of the apparent lead times are exaggerated, since the Air Force systems shown are not necessarily the first ones to use the technology. (For example, since the B-1 was not the first plane with a variable swept wing, the 20-year lead time shown in figure 4 is not an accurate measure of the time needed to get this technology into the field.) Nevertheless, this illustration does suggest that typical technologies now being fielded in military systems began their development 10 to 15 years ago.

The lead time needed to field new technology can be reduced in three ways: a nation can, by spending more or by spending more efficiently, increase the rate at which military systems are modernized; it can hasten the rate at which new technologies are included in proposed system designs; and it can speed up the acquisition process by which any particular new system gets into the field. Although these different aspects—**affordability, insertion**, and **acquisition**—are discussed separately in this chapter, it is important not to treat them in isolation. Even though the strategy of the United States depends upon maintaining a technological advantage, that advantage can be realized only when technology leads to increased military capability. Introducing new state-of-the-art technology into a military system has no benefit if the system cannot be developed, if it cannot be supported and maintained in the field, or if it is prohibitively expensive.

This chapter first looks at the affordability issue, one which cuts across all activities of DoD and is a critical determinant of the rate at which forces are modernized. It then examines factors that influence the selection of new technologies when upgrade decisions are made, and it concludes with a discussion of the DoD acquisition system itself—the process by which decisions to modernize are implemented.

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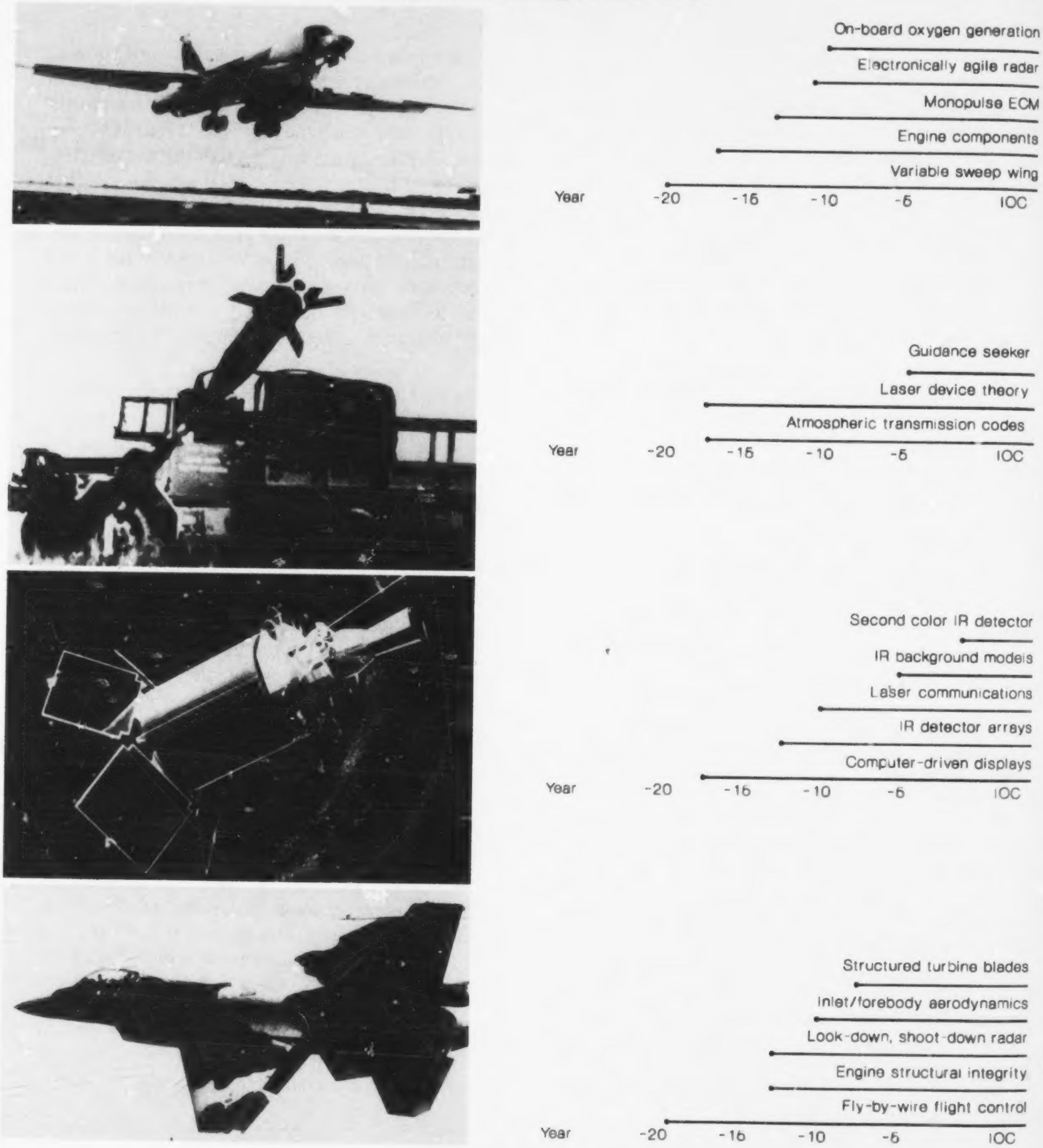
[1] U.S. Department of Defense, "Soviet Military Power: An Assessment of the Threat, 1988," 1988, p. 149.

[2] Defense Science Board, "Report of the Defense Science Board 1987 Summer Study on Technology Base Management," prepared for the Office of the Under Secretary of Defense for Acquisition, December 1987, p. E-2.

Figure 4—Technological Lead Times



SOURCE: U.S. Air Force, Headquarters Air Force Systems Command, Deputy Chief of Staff/Technology and Requirements Planning, *The Air Force Science & Technology and Development Planning Program*, June 22, 1988.

AFFORDABILITY

Funding Shortfalls

The biggest impediment to fielding state-of-the-art technology in future weapons systems may not be getting the technology into the design; it may not even be getting the design through the acquisition process and into the field. The biggest problem may be finding the money to buy the new system in the first place.

After undergoing unprecedented peacetime growth during the early part of the Reagan Administration, the DoD budget faces equally unprecedented shortfalls in future years as existing plans far exceed likely available funding. Two factors are leading to this squeeze. One is the "bow wave," representing the bills yet to be paid for weapon systems that are now undergoing development or entering production. The second, termed the "stern wave," represents the rising cost of supporting and maintaining weapons that have already been delivered. DoD data show that operations and support (O&S) expenditures for new generations of weapon systems often exceed those of the systems that are being replaced. Although technological improvements sometimes actually reduce O&S costs, the Comptroller General of the United States has stated that expectations to this effect generally "are not being fulfilled."[3]

Then Secretary of Defense Carlucci stated that between $174 billion and $300 billion will have to be cut from the planned DoD program for fiscal years 1990 to 1993,[4] assuming that the defense budget will rise at a rate of 2 percent over the inflation rate. Given the present $140 billion budget deficit, the Gramm-Rudman-Hollings spending limits, and other Federal obligations such as cleaning up years of environmental neglect in the nuclear weapons production complex, these increases in the DoD budget may not be realized. A DoD budget that only keeps track with inflation will fall short of one with 2 percent real growth by another $36 billion over the next 4 years; one that only remains level in current (not constant) dollars falls short by much more. Clearly, as the Comptroller General has said, "the services have too many systems chasing too few dollars."[5]

Much of the problem is that the cost of new systems is increasing at a rate that consistently exceeds inflation. This does not necessarily mean that the money is being wasted, since the quality and performance of these systems is going up as well. However, given fiscal constraints, this cost growth will severely limit the quantities of new systems that can be purchased. Norman Augustine, president and chief operating officer of a major aerospace firm, drives this point home in a striking way. Extrapolating current trends in tactical aircraft cost growth (figure 5), he finds that the U.S. defense budget will be able to afford only one plane in the year 2054, and that the plane's successor some 75 years later will consume the entire Gross National Product (GNP).

Aging Inventories

Inability to complete ongoing modernization programs at planned rates—even given the recent budget buildup—aggravates what is already a slow recapitalization rate within DoD. According to Leonard Sullivan in an analysis conducted for the Center for Strategic and International Studies'(CSIS) Defense Acquisition Study:

> The total fiscal year 1986 replacement value of all DoD facilities and properties ran just under $3 trillion—about 75 percent of the U.S. GNP. Based on current [in 1985] acquisition plans, DoD is "rolling over" its weapon and support systems roughly once every 25 years and its fixed facilities once every 50 years. No commercial enterprise operates with such slow turnover. It would appear difficult if not impossible to keep defense at high readiness and near the leading edge technologically with this poor replacement rate.[6]

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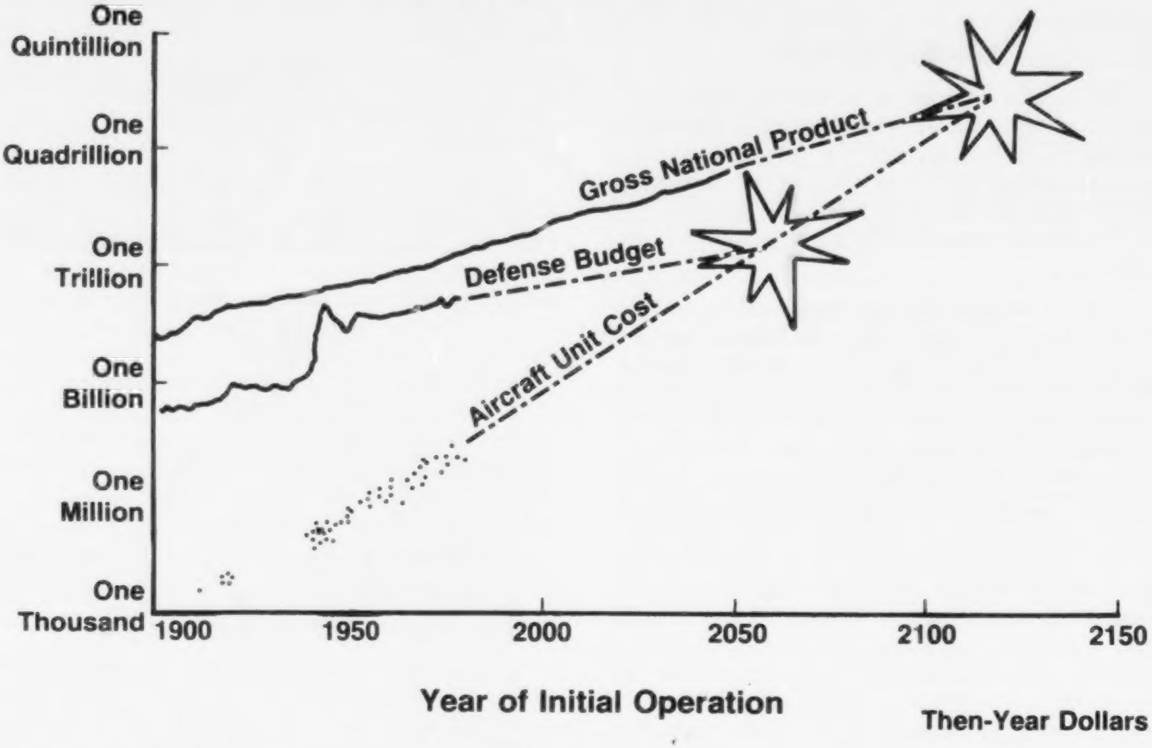
[3] Charles A. Bowsher, Comptroller General of the United States, quoted in George C. Wilson, "Pentagon Bracing for Two Waves: Rising Costs Threaten Weapons, Readiness," *The Washington Post*, Nov. 13, 1988, p. A1.

[4] The Secretary of Defense's remarks are referred to in the Statement by Charles A. Bowsher, Comptroller General of the United States, before the Senate Committee on Armed Services, Mar. 14, 1988, p. 9.

[5] Ibid.

[6] Leonard Sullivan, Jr., "Characterizing the Acquisition Process," paper presented at the Center for Strategic and International Studies Conference on U.S. Defense Acquisition, November 1986, Washington, DC, pp. 2-3. (Commissioned for U.S. Defense Acquisition: A Process in Trouble, the CSIS Defense Acquisition Study).

Figure 5—Projected Future Costs of Tactical Aircraft



SOURCE: Norman R. Augustine, *Augustine's Law* (New York, NY: Penguin Books, 1983), p. 142.

Sullivan also points out that major systems—at least platforms such as aircraft and ships—can easily still be in service 40 years after they entered full-scale development. With systems replaced, on average, every 25 years, aging systems remain in active service for a long time.

A study done by the DSB in 1984, during the peak of the Reagan buildup, concluded that:

> . . . many major equipment inventories will experience a steady aging during the remainder of this century, [and] *an increasing share of the necessary force modernization of the future must occur through the upgrading of equipment already in inventory or already committed to production.*[7]

Figures 6, 7, and 8 show the increasing average age of Army tanks and attack helicopters and Air Force cargo aircraft.[8] Many other weapons categories—although certainly not all—also show increasing average ages.

The DSB study, while basically optimistic about the potential for upgrades, did identify some areas

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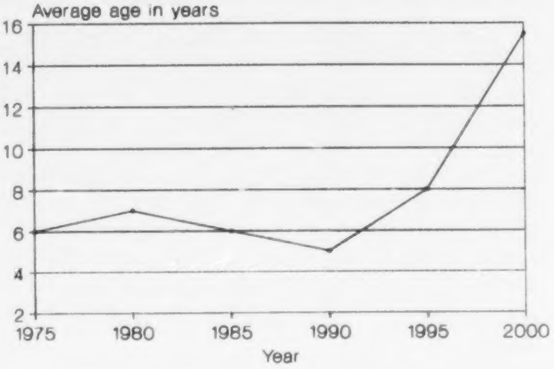
[7] U.S. Department of Defense, *Improved Defense Through Equipment Upgrades: The U.S. and Its Security Partners*, Final Report of the 1984 Defense Science Board Summer Study on Upgrading Current Inventory Equipment, November 1984, p. 2. (Emphasis in original.)

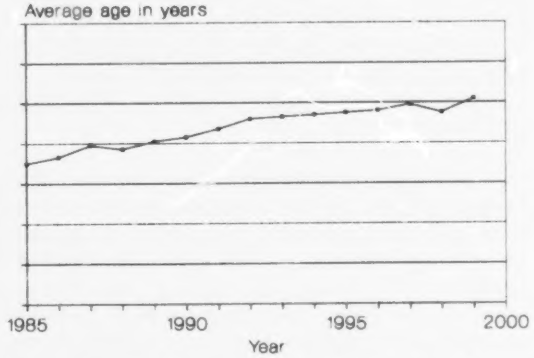
[8] Although the DSB study did not give the source of the data from which these graphs were derived, the office of Donald Rice (President and Chief Executive Officer of the Rand Corporation), who chaired the study, confirmed that they were calculated from the long-range Extended Planning Annexes of the Services. In the past, such long-range plans have tended to overestimate future weapons purchases, due both to underestimating weapon cost and to overestimating available funds.

Figure 6—Projected Average Age of U.S. Army Tank Inventory



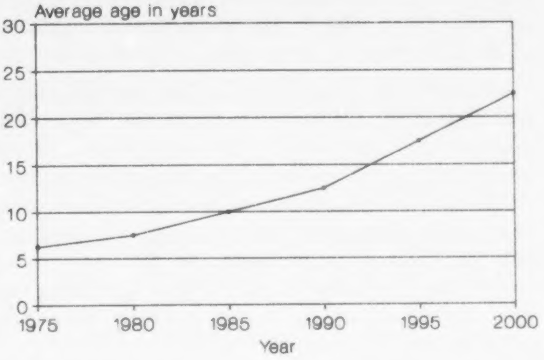
SOURCE: U.S. Department of Defense, *Improved Defense Through Equipment Upgrades: The U.S. and Its Security Partners*, Final Report of the 1984 Defense Science Board Summer Study on Upgrading Current Inventory Equipment (Alexandria, VA: Defense Technical Information Center, November 1984).

Figure 7—Projected Average Age of USAF Cargo Aircraft Inventory



SOURCE: U.S. Department of Defense, *Improved Defense Through Equipment Upgrades: The U.S. and Its Security Partners*, Final Report of the 1984 Defense Science Board Summer Study on Upgrading Current Inventory Equipment (Alexandria, VA: Defense Technical Information Center, November 1984).

Figure 8—Projected Average Age of U.S. Army Attack Helicopters



SOURCE: U.S. Department of Defense, *Improved Defense Through Equipment Upgrades: The U.S. and Its Security Partners*, Final Report of the 1984 Defense Science Board Summer Study on Upgrading Current Inventory Equipment (Alexandria, VA: Defense Technical Information Center, November 1984).

for improvement.[9] It found that the Services seem reluctant to pursue major upgrades for weapons systems they are trying to replace, and that a "systemic bias" against upgrades results from consistently underestimating system lifetimes. Since the Services are reluctant to upgrade systems that they expect to retire soon, underestimating service lifetimes thwarts upgrades.[10]

The DSB study also concluded that upgrade plans should be part of a comprehensive modernization for an entire equipment category, including upgrades and new starts. Moreover, upgrading is much easier if provided for in the original design of the system to be upgraded.

Policy Options

The future shortfall in procurement funding can be met in the short term only by reducing procurement expenditures or by making cuts elsewhere in the DoD budget. The magnitude of the task, involving cuts of hundreds of billions of dollars from future DoD budgets, will certainly curtail our ability to sustain a technological advantage through force modernization. Moreover, cuts of this magnitude will have effects that go far beyond hindering the introduction of new weapons systems and the upgrade of older ones. They will affect overall national security policy, strategy, and goals that lie far outside the scope of this study. Therefore, this study does not attempt to present a complete discussion of the options facing military planners, but will instead sketch out the implications of some of the choices.

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[9] Defense Science Board, op. cit., footnote 7, p. xii.

[10] Every one of the almost 40 helicopters, fighters, attack aircraft, and antisubmarine warfare aircraft fielded by the Navy since the early 1950s has remained in active service longer than planned, some by over 20 years. The study concluded (p. 2) that there is "every reason to believe that this picture reflects the experience of the other Services, too."

Distinctions must be drawn between short-term and long-term solutions. Solutions that might best improve the situation in the long run, such as improving the efficiency of the acquisition process or restricting the number of new starts, will take years to produce substantial savings and will not help the short-term problem. At the same time, short-term fixes such as deferring or stretching out weapons acquisitions will only make the long-term problem worse.

Short-Term Measures

To balance the procurement budget in the short term, either the cost of new systems must be reduced or else more procurement funds must be made available by cutting other areas. Options for reducing the aggregate cost of new systems involve three different approaches: funding deferral, cancellation, or upgrading existing systems.

Stretchouts or Funding Deferrals—This option has been the traditional choice for handling funding crises in the defense budget. It has the advantage of being politically much easier than canceling programs outright, and it avoids having to write off previous investments. However, it is one of the least attractive solutions for the long run. Not only are costs deferred, rather than eliminated, but those deferred costs are increased due to keeping infrastructure and support on standby, inefficiencies imposed by lowering production rates, changing program plans, and inflation. Stretching out some programs can provide room in the budget for other important modernizations to proceed. However, stretchouts exacerbate program variability, one of the most-cited problems with defense acquisition.

Canceling Programs—Although canceling programs forces writing off sunk costs, at least those costs do not come back to haunt budget planners in future years. Moreover, some of the investment can often be recouped in future programs that draw upon technology developed in the canceled program. The earlier in development a program is canceled, the less the sunk cost will be and the sooner those resources can be directed to other goals.

However, program cancellation is extremely difficult, considering the balancing act of negotiation and compromise within DoD and between DoD and Congress required for programs to be approved in the first place. Ideally, those programs judged to have the lowest military utility of all active programs should be the first ones to be eliminated in times of fiscal constraint. But, there is no universally accepted, objective measure that can help make this determination. Program cancellations—like program approvals—inevitably involve political judgments.

Upgrade Rather Than Replace—The 1984 DSB study cited above recommended that system upgrades, rather than replacements, be emphasized more heavily in the future. To the extent that present system design makes this possible, increasing emphasis on upgrades is likely to be an attractive option for permitting modernization of systems we cannot afford to replace. This option will not work, however, if the military Services see upgrades as threats to their long-term plans for future acquisitions. More realistic estimates of the service lifetimes of existing systems will be needed for making valid upgrade decisions.

To promote upgrades, proposals for new acquisitions could be required to include detailed comparisons of the relative merits of replacing v. upgrading an existing capability. The office of the Under Secretary of Defense for Acquisition [USD(A)] would be an appropriate place for such a review to be conducted, and it could provide inputs independent of the requesting Service.

Besides reducing spending on new systems, funds could be devoted to procurement by making cuts in other areas. Options for cuts elsewhere in the DoD budget include:

Reducing Research, Development, Testing, and Evaluation (RDT&E)—As was pointed out in OTA's previous report on the defense technology base,[11] R&D is always vulnerable to budgetary cuts because its benefits are difficult to measure. Moreover, cutting R&D appropriations in a given fiscal year reduces actual spending that year by much more than the same size cuts in other areas, such as procurement. Cuts in RDT&E funding at first glance would seem to threaten the U.S. strategy of compensating for quantitative inferiority by technological superiority, since that technological superiority has traditionally arisen from the DoD technology base programs. **Upon further examination, however, a military strategy that depends on increasing the technological sophistication of weapons systems to the point where they can no longer be afforded does not provide a sound foundation for national security.** Reevaluating the role that RDT&E plays in national security is a long-term, rather than short-term, measure; accordingly, it is mentioned again in the discussion of "Longer Term Measures."

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[11] U.S. Congress, Office of Technology Assessment, *The Defense Technology Base: Introduction and Overview—A Special Report*, OTA-ISC-374 (Washington, DC: U.S. Government Printing Office, March 1988), especially pp. 35-36.

Reducing the Operations and Support Budget— Cuts in O&S budgets, like cuts in RDT&E, have the advantage of yielding relatively larger reductions in outlays for that year than cuts in procurement. These cuts are therefore attractive in the short run. However, making effective use of our substantial investment in defense systems and personnel requires that systems be maintained and supported and that people be trained. Therefore, reductions in O&S funding would probably not be the most cost-effective way to reduce the DoD budget in the long run. Components of the O&S budget, however, can certainly be reduced. The General Accounting Office (GAO) has identified improvements that could be made, for example, in logistics and spare part inventories.[12]

Reducing Military Forces—In testimony before the Senate Armed Services Committee, the Comptroller General stated that budget restrictions may force the United States into reducing its level of military personnel. "We may also have to rethink some of our worldwide commitments in light of our budgetary resources."[13] This study will not presume to speculate as to which commitments this country could afford to cut back on. However, any reductions in personnel, operations and support, and procurement might have the effect—planned or otherwise—of limiting this nation's ability to fulfill its commitments. Reevaluating those commitments in the light of budgetary pressures represents not so much a decision to let budgets drive policy, as a recognition that they do so whether that is desirable or not. It would be preferable to start with the decision to limit obligations and reduce spending accordingly, rather than let budget cuts limit those commitments arbitrarily.

One difficulty with reducing forces to save money is that personnel reductions could involve offering early retirements and redeeming accrued leave, which might actually cost more money in the short run than retaining people on full salary.

Reducing Civilian Personnel—DoD employs over a million civil servants. Without doing a bottom-up review as to how all these personnel are employed, it is difficult to specify where reductions could be made. However, many have suggested that such reductions not only would save money but also would improve DoD operation. The Packard Commission recommended "a substantial reduction in the total number of personnel in the defense acquisition system, to levels that more nearly compare with commercial acquisition counterparts."[14] However, the likelihood that personnel reductions may not save much in the short term applies to civilian personnel as well as military.

Longer Term Measures

Reexamine National Defense Commitments— This option is the long-term continuation of the short-term option of "Reducing Military Forces." This nation's long-term defense needs must—by definition—meet its long-term defense budget. Whether the adjustment is made by lowering commitments or by raising additional funds, a deliberate, well thought-out examination of national priorities may be required. Like any other consensus-building process that sorts out competing interests among constrained resources, this process is inherently political. It would require a continuing effort.

Improve Acquisition Efficiency—Although the defense acquisition system probably does spend more than an acquisition system designed for optimum efficiency would, those excess costs are often inherent in the political process surrounding defense acquisition and in other cases are the price we pay for pursuing national goals unrelated to defense. Reducing many of these costs could require Congress and the American public to reexamine the value they currently attach to oversight and review, as well as the cost they are willing to pay to pursue a clean environment, fair labor practices, equal opportunity, and many other objectives.

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[12] Charles A. Bowsher, op. cit., footnote 3, p. 11.

[13] Ibid.

[14] Ibid.

If savings in the acquisition process could be identified—either through eliminating waste or by choosing to relax various requirements that drive up costs—it would take many years for those savings to result in substantially lower system costs. The vast majority of the total life-cycle cost for systems now in development has already been determined.

Reduce or Reevaluate Research, Development, Testing, and Evaluation—The President's Blue Ribbon Commission on Defense Management (the Packard Commission) recommended that "DoD should place a much greater emphasis on using technology to reduce cost—both directly by reducing unit acquisition cost and indirectly by improving the reliability, operability, and maintainability of military equipment."[15] Cuts in the RDT&E budget, were they selected to address the affordability problem, could be associated with a reevaluation of how well the DoD technology base serves the goal of cost reduction, in addition to—or instead of—the more traditional goal of enhancing performance. Note also that increasing the emphasis placed on simulation, as opposed to hardware development, can reduce RDT&E costs to the extent that the simulations are valid. Increased computational capability, along with growing experimental databases, can improve the validity of simulations.

Enforce Budgetary Discipline—One policy choice here could be to require the Services to make life cycle cost estimates of new systems for longer terms than they do today, and to prevent them from starting new programs unless they provide room in these longer-term budgets to develop, produce, and support the future systems. However, not only would such a requirement demand accurate cost estimates for the operation of systems that have not yet been developed—almost a contradiction in terms—but it would also require dependable projections of future Service budgets, a task that has proven no easier. Moreover, this exercise would be of little use unless pressures within government and industry to underestimate the costs of new systems in order to fit them into future funding requests can be mitigated. These issues are discussed further in the section on acquisition.

Consolidate Missions of Weapon Systems—According to the Comptroller General, greater efficiencies will have to be obtained in a number of areas such as families of equipment that now fulfill common missions. For example, several different types of weapon systems, from shoulder-mounted rockets to tanks to aircraft, in the past have been developed to attack tanks. "While some variety of systems is probably desirable, we must exercise greater restraint in the future because we cannot afford to replace weapon systems on a one-for-one basis."[16]

Realigning the assignments of weapon systems to missions will involve substantial analysis on the part of the military Services. It may even require readjusting the Services' respective roles and missions, if it is determined that tasks presently assigned to one Service will in the future be accomplished by upgrading or replacing a weapon system operated by another Service. Firm guidance from the Office of the Secretary of Defense (OSD) and the Joint Chiefs of Staff (JCS) will be required to make the necessary trade-offs.

TECHNOLOGY INSERTION

Making room in the budget to update or replace a system does not automatically ensure the introduction of the latest technology. In fact, relatively few systems developments or upgrades are undertaken solely to exploit a specific new technological capability:

> Of the many scores of major acquisitions currently in progress, fewer than a handful are responding to genuinely original military needs (such as ASAT [anti-satellite weapons]) or to a truly revolutionary

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[15] "A Quest for Excellence: Final Report to the President," by the President's Blue Ribbon Commission on Defense Management, June 1986, p. 56.

[16] Charles A. Bowsher, op. cit., footnote 4, p. 11

> Soviet threat that challenges U.S. technological prowess. Possibly 95 percent of current acquisition programs are basically aimed at making marginal threat-related improvements at the same time that they offset depreciation of aging inventories with something new.[17]

In the majority of cases where the primary motivation for an upgrade or replacement is modernization, the introduction of new technology is neither easy nor automatic. Although there have been significant exceptions, DoD has traditionally not been very successful at taking advantage of new technologies that were promoted by their developers ("technology-push") in the absence of an interested constituency among the technologies' eventual users ("requirements-pull").

Those responsible for planning and developing military systems should ensure that the potential increased capability made possible by new technology justifies the risks—in cost, schedule, and possibility of failure—inherent in that technology's development. In the case of obsolete equipment, for example, putting any replacement at all in the field is usually more important than including the latest technological features. This conservatism poses barriers that must be overcome before new technologies can be fielded.

To the degree that proven technologies are not fielded, or promising technologies are not investigated, those barriers are inappropriate. However, they should not be eliminated completely. It is not, after all, the mission of DoD to deploy new technology for its own sake. Unproven and high-risk technologies that cannot be developed successfully will not improve our military capability no matter what their ultimate potential may be. Moreover, just because a technology is new and effective does not mean that it is the best solution to any particular problem.

The Technology Insertion Process

Technology insertion depends, of course, on the entire acquisition process, which is discussed more generally at the end of the chapter. It refers specifically to the process by which technical developments in the laboratory are selected for use in new weapon systems.

The office of the USD(A) was established in part to combine jurisdiction over research and development with that over production. However, there is a very significant discontinuity between technology base activities and the later stages of full-scale development and production. Technology base activities are undertaken with potential military relevance or application in mind, but they are generally not targeted specifically towards a particular system requirement. Instead, they are managed and directed according to their field of science or technology, and they serve to stock the shelves of the "technology supermarket" from which designers of new systems later draw.

When a requirement for a new military system becomes formalized, at least for major systems, funding and responsibility for that system is assigned to a System Project Office (SPO) dedicated to satisfying that particular requirement. It might be expected that developing a major new weapons platform—ship, aircraft, land vehicle, or spacecraft—would ease the introduction of advanced technology through new generations of subsystems and components; in fact quite the opposite can occur. In today's political environment, where a conspicuous failure can be used to delay or scuttle a new program, proponents may choose to outfit an entire platform with existing systems to minimize the risk of failure. Then to take full advantage of the capability offered by the new platform, its component systems must be upgraded with new ones after the platform becomes operational. Providing for upgrades in advance makes those upgrades easier and more effective. However, technology might be introduced still faster if new platforms were designed to take better advantage of new components and systems from the beginning.

When a new system or subsystem is undergoing development, its funding is generally in budget category 6.4, engineering development, and responsibility for the system lies primarily with the industrial contractor or contractors that won the development contract. **Thus, detailed design of military systems, including the selection of technologies for use, is primarily the responsibility of designers in private industry.** Of course, these designers do not work in isolation; their bids must respond to government request, and the bids are evaluated by government employees. SPO obviously has overall direction and responsibility for the project. However, it is significant that the project office personnel are largely separate from the people who fund and execute R&D within government agencies and laboratories.

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[17] Leonard Sullivan, Jr., op. cit., footnote 6, pp. 18-19.

Several mechanisms help bridge the gap between technology base activities and the design and production of particular military systems. The most indirect might be termed **technical diffusion**, by which findings and results of (unclassified) technology base funded activities appear in the open literature and become available for use.[18] Interaction between those doing R&D in a generic field of technology and those responsible for designing particular systems is an important transfer mechanism, as is the actual transfer of personnel from technology base activities to systems engineering. Although technical interchange is essential in promoting the development and application of defense technology in this country, there is concern that increased diffusion could also allow this information to pass to potential adversaries. Therefore, the government has attempted to restrict export of technical information, and there is considerable controversy as to the net benefit to the United States of these restrictions.[19]

More direct mechanisms to bridge the "transition gap" include **Independent Research and Development (IR&D)** conducted by industry and (in the case of defense contractors) partially reimbursed by the government as an allowable charge on government contracts. Through IR&D, industrial scientists and engineers—with feedback from government evaluators—can explore technologies and gain sufficient expertise with them to feel confident enough to prepare bids proposing their use in new systems. Industry retains ownership of intellectual property developed through IR&D.

In **contract research and development**, the government funds and retains ownership of the development of a particular technology, component, or subsystem. The research findings and technical data resulting from such contracts may be made available to others, subject to classification and export control restrictions. Even without proprietary rights, the contractor winning such a contract benefits directly by developing "hands-on" experience with the technology; other companies benefit indirectly from the reports and technical data and may find themselves forced by competitive pressures to develop an equivalent capability. Much of this type of development is funded through budget categories 6.2 and 6.3.

Perhaps the most direct means for transferring technology from the laboratory into systems is budget category **6.3A, advanced exploratory development**. Category 6.3A includes funding for non-system-specific prototypes or technology demonstration experiments intended to validate technologies to the satisfaction of those—either within the system project offices or private industry—who will ultimately recommend or select those technologies for use in future systems.

None of these transfer mechanisms resembles what one government laboratory official characterized as the fictitious "midnight loading dock" approach by which a government lab develops a prototype and leaves it out overnight for an industrial contractor to pick up, duplicate, and churn out many identical copies. In reality, the relative roles of government scientists, government project office sponsors, and industrial developers are far more complex. Since the path by which technologies developed in government laboratories end up in system designs is so indirect, it can be difficult to trace the contributions of the labs. Technologies developed in, or whose development is sponsored by, the government laboratories are picked up by industry, where they are further developed, refined, perhaps put to new uses, and eventually incorporated into system designs. By the time they end up in bid proposals, their origins in government-conducted or government-sponsored research may no longer be apparent.

The preceding discussion of technology insertion applies to new system developments in which industry designs and builds a system to meet specific military requirements. To the extent that the military is able to use commercial products, either as they are or with minor modification, it can bypass the lengthy development process and proceed to apply the technology embodied in those commercial products directly to military use. In many areas, commercial technology leads that available in the defense sector. Such an emphasis on **non-developmental items** is discussed in other chapters of this report that analyze dual-use technologies and their relevance to military needs.

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[18] Classified findings are also disseminated through classified journals and seminars. However, the audience is restricted to those holding appropriate clearances who can demonstrate a "need to know" the classified information.

[19] The export control controversy is discussed in depth in a recent study by the National Academy of Sciences: National Research Council, *Balancing the National Interest: U.S. National Security Export Controls and Global Economic Competition* (Washington DC: National Academy Press, 1987).

Previous Studies

Several prior studies have addressed difficulties in fielding state-of-the-art technology in military systems. The same factors often crop up in analyses done years apart, showing that understanding a problem does not automatically lead to a solution in the face of unwillingness or inability to make changes. In other cases, problems identified in different studies appear to contradict each other.

1981 DSB Study on Technology Base[20]

In 1981, the DSB issued a report on the technology base. In addition to identifying crucial technologies to be emphasized and evaluating the current government technology base investment and operation, this study identified a number of barriers inhibiting successful transition of technology into systems:

- Discontinuity of funding, indecision, and the short-term orientation of many key decision makers.
- The organizational and physical separation within DoD of technology base activities and system development.
- Little emphasis on technology demonstrations that can illuminate risks, costs, and payoffs of using new technology.
- Little emphasis on "test marketing," or developing a constituency among the system developers for using new technological developments.

The study found that "there is a strong incentive to pursue low risk options" and that "incremental improvement is one of the biggest enemies of innovation."[21] It recommended creating an "Advanced Projects Agency" separate from the Defense Advanced Research Projects Agency, or DARPA. This proposed new agency, to be staffed by personnel from the military Services, would develop experiments to quantify the maturity of emerging technology, conduct the "test marketing" experiments mentioned above, and protect funding for these experiments from being tapped for other needs. In the absence of such an agency, the study strongly recommended that more funding be allocated to category 6.3A, in any case, to conduct these experiments. After concluding that DoD does not make effective plans for inserting technology throughout the life of a system, the panel recommended that technology insertion plans be made a basic and fundamental part of program planning.

1985 DSB Summer Study on Practical, Functional Performance Requirements[22]

This study examined a number of DoD programs, concentrating on the earliest parts of the acquisition process during which the requirements for systems are determined. In apparent contrast to the 1981 DSB study, which accused system developers of being overly conservative in their choice of technologies, this study concluded that developers tended to reach too far. "The foremost factor associated with unsatisfactory program outcomes was that the technology, usually after the fact, was assessed as being unready for entry into engineering development." Like the 1981 study, however, this DSB panel also highlighted the need for objective measures of maturity. "It is likely that in almost every case of failure the project's initiators *believed* at the time of initiation of engineering development that the technology was, in fact, mature."[23]

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[20] Defense Science Board, "Report of the Defense Science Board 1981 Summer Study Panel on the Technology Base," prepared for the Office of the Under Secretary of Defense for Research and Engineering, November 1981.

[21] Ibid., pp. IV-3, IV-5.

[22] Defense Science Board, "Report of the Defense Science Board 1985 Summer Study on Practical Functional Performance Requirements," prepared for the Office of the Under Secretary for Research and Engineering, March 1986.

[23] Ibid., p. 20. (Emphasis in original.)

GAO Letter on Technology Transition, January 1987[24]

Upon concluding its review of the transition of technology base activities into weapons acquisitions, GAO did not issue a formal report or make recommendations. Its Associate Director for National Security and International Affairs did, however, write the Secretary of Defense expressing concern that "early demonstrations of advanced technologies have not received adequate management attention at the Office of the Secretary of Defense level." GAO found that the "most significant barrier" to effective transition is the lack of emphasis on such demonstrations, and it cited recommendations of the Packard Commission highlighting the benefits of early prototyping. GAO called attention to the low budget priority and decentralized decisionmaking approach given to such demonstrations. In response, the USD(A) agreed with the importance of early technology demonstration, conceding that the budget for such activities had remained level in constant dollars during the period reviewed by GAO.[25] He noted that funding for technology demonstration was projected to double over the next 5 years.

1987 Defense Science Board Summer Study on Technology Base Management[26]

This DSB panel found that "both the Defense Department and commercial industry are seriously deficient in rapid technology transition from R&D to systems and products." Like the GAO and the two preceding DSB studies, this DSB panel concluded that the "greatest opportunity to improve the rate and effectiveness of this transition process is by increasing focus on the early advanced development phase of the S&T [science and technology] program, that is, Budget Category 6.3A." According to the panel, 6.3A activities should include building and testing experimental systems in field environments to establish feasibility and utility before a commitment is made to full-scale engineering development.

Army Science Board Summer Study on Technology Insertion[27]

The Assistant Secretary of the Army for Research, Development, and Acquisition asked the Army Science Board (an advisory body to the Secretary of the Army analogous to the Defense Science Board) to survey the Army, DoD, and industrial technology bases to identify candidates for insertion into Army systems, to evaluate the cost and effectiveness of the Army technology insertion process, and to review the Army acquisition process to recommend changes. The panel found that:

- New technology will have to be inserted in a timely manner into fielded systems. Introduction of new systems will be severely limited by future funding pressures and (particularly for the Army) by delays or cancellations of major systems, such as the LHX (Light Helicopter Experimental) and the DIVAD (Division Air Defense gun).
- "To understand how technology insertion can address cost and system effectiveness, technologists must understand operational problems . . . The payoffs from the technology base usually come from combining of technologies by *system developers* who know available technical options and can see how to use them."[28]
- Basing technology selection on acquisition cost alone will always result in selection of the "low risk, low cost, low technology approach." New technologies have their biggest payoff in life-cycle, not acquisition, costs.[29]
- Acquisition personnel are insufficiently experienced.
- The budget process is a problem.

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[24] Michael E. Motley, Associate Director, National Security and International Affairs Division, General Accounting Office, letter to Caspar Weinberger, Secretary of Defense, Jan.16, 1987.

[25] Richard Godwin, Under Secretary of Defense for Acquisition, letter to Michael Motley, Associate Director, National Security and International Affairs Division, General Accounting Office, May 18, 1987.

[26] Report of the Defense Science Board, op. cit., footnote 2, December 1987.

[27] Army Science Board, "Army Science Board 1988 Summer Study on Technology Insertion in Army Systems," prepared for the Assistant Secretary of the Army for Research, Development, and Acquisition, in press.

[28] Ibid., p. 33. (Emphasis in original.)

[29] Ibid., p. 57.

Analysis and Policy Options

The problems identified in the studies cited above fall into three general categories. Those pertaining to the discontinuity of funding, the short-term focus of decision makers, the budget process, and personnel affect the entire acquisition process and are discussed in the concluding section of this chapter (see "The Defense Acquisition System"). Another set of problems relates to technological overoptimism or extreme conservatism and the consequent need for objective assessments of the maturity of a technology. These issues can be addressed by increasing the emphasis put on prototyping and technology demonstration experiments, as well as by building product improvement cycles into system design. Finally, a third set of problems addresses the organizational separation between technology base activities and systems developers, the lack of "test marketing" new ideas, and the lack of a constituency for technological advances within the "user" communities. These issues can be addressed by an organizational structure that attempts to bridge the gap between the laboratory and the system developer, placing the ultimate users of a technology in more of an "ownership" position and therefore making them more receptive to the use of that technology.

Prototyping and Technology Demonstration

Most of the studies cited above argued for increased reliance on prototyping and technology demonstration. The Packard Commission found that making trade-offs between the risks and benefits of state-of-the-art technology requires reliable information, and that "the only consistently reliable means of getting such information is by building prototypes that embody the new technology." It recommended that "prototyping, either at the system or critical subsystem level, be done as a matter of course for all major weapon programs."[30]

Earlier studies had cautioned against overemphasizing prototypes. Almost 10 years before the Packard Commission reports were issued, a DSB summer study analyzing the acquisition cycle concluded that "the widespread or mandatory use of full-scale system prototypes for all programs up to the production prototype level is frequently wasteful of critical national resources—dollars and manpower as well as time."[31] This panel was particularly opposed to the contemporary practice of forcing industrial contractors to fund large costly prototypes out of their own resources. However, at the component or subsystem level—rather than the system level—the panel concluded that competitive prototyping could significantly reduce the cost and time needed to make a full-scale development decision. In summary, the report found that prototyping could be "a sound and useful practice in major system acquisitions provided that the candidates for the use of prototypes are carefully selected, that only those things are prototyped which really need verification, and that prototypes are not considered to be some form of 'free lunch' for the procuring agency [e.g., by forcing contractors to pay for them]."[32]

Advanced Technology Transition Demonstrations—The 1987 DSB report on technology base management placed a heavy emphasis on Advanced Technology Transition Demonstrations (ATTDs), which it saw as an extension of the Packard Commission prototyping recommendations to include technologies that are not necessarily committed to defined system developments. This distinction is important. Prototypes are test versions of military systems that have been designed to meet particular military requirements. "Demonstrations," on the other hand, provide opportunities to test technologies that are militarily relevant; but they do not in themselves represent designs of specific systems. The technologies they demonstrate, if successful, could be implemented in future systems. (Note that if a technology demonstration were realistic and successful, there would be less need to prototype a follow-up system using that technology.)

ATTDs, according to the DSB panel, should follow several basic guidelines:

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[30] President's Blue Ribbon Commission on Defense Management, "A Formula for Action: A Report to the President on Defense Acquisition," April 1986, pp. 18-19.

[31] Defense Science Board, "Report of the Acquisition Cycle Task Force 1977 Summer Study," prepared for the Office of the Under Secretary for Research and Engineering, Mar. 15, 1978, p. 53.

[32] Ibid., p. 54.

- They should reduce technical risk by demonstrating a technology's potential and maturity in an "operational," rather than "laboratory," environment.
- They should show a potential for new or enhanced military capability, or for a significant improvement in cost effectiveness.
- They should be accompanied by a technology transition plan at the outset of the demonstration. That is, potential applications and opportunities to implement the technology should be identified at the start, rather than the conclusion, of the demonstration process.
- They should involve the participation of both the developer of the technology (typically a Service Systems Command) and the system's ultimate user (an Operating Command). The user should serve as sponsor, with the developer as project manager.[33]

According to the DSB panel, a successful ATTD would clarify the definition of the military need that the technology is to meet; stimulate strong acceptance and sponsorship of the innovation among its ultimate users; combine viewpoints of the research, development, production, and operational communities; clearly prove both the maturity of the technology and the satisfaction of a perceived military need; provide visibility to those higher levels within DoD and the Congress that will ultimately approve subsequent developments; and ensure adequate financial support to meet the goals of the project and initiate follow-on development.

Given a limit on resources allowable for such demonstrations, together with the need to provide enough funds to do a meaningful experiment (estimated by the DSB panel as typically $10 million to $100 million over 3 years), ATTD candidates would have to be selected competitively. This competition should ensure that the best ideas get funded. The DSB panel urged that funding for these ATTDs be "fenced off" from other R&D needs so that overruns on large, more immediate demonstrations do not threaten the many smaller, longer-term R&D projects. (What this means in practice, of course, is either that provision should be made in advance for overruns when preparing project budgets, or else that overruns should be covered from somebody else's pot.[34])

The panel urged that these ATTDs be conducted within the existing military Service and defense agency acquisition procedures, and not centralized DoD-wide. The various Services now have somewhat different practices concerning their 6.3A budgets. Most of the $2 billion now spent within 6.3A is less focused, less field-oriented, and longer-term than the proposed ATTDs would be. The DSB panel recommended that, by 1991, each Service devote half its 6.3A budget to ATTDs, sufficient to fund a total of 20 to 30 projects.

***Existing Technology Demonstration Programs*—** At present, the Navy and the Air Force each have a program embodying many of the principles recommended by the DSB for ATTDs. **In essence, both involve establishing an agreement between the developer and the user that if the technology is successfully demonstrated, it will be used; the criteria for success are jointly developed at the outset.** Prior agreement is required both to establish a sense of sponsorship in the user and to ensure that the user reserves sufficient flexibility in its out-year budget requests to make funds available for the program once it has been successfully demonstrated.

DARPA, for its part, has significantly increased its role in prototyping technologies. This increased role has proven controversial.

Navy—The Navy has the smallest 6.3A program of the three Services, totalling $189 million in fiscal year 1989. Part of this 6.3A program represents generic technologies—such as explosives development—that contribute to many weapons systems. The remaining part of the 6.3A budget provides candidates for Advanced Technology Demonstrations (ATDs), which formed the model for the DSB recommendation regarding ATTDs (see table 5).

Navy ATDs are funded through the Navy-wide 6.3A account and are not funded or managed by the commands responsible for the development of particular new systems. ATDs therefore provide an opportunity to demonstrate a high-risk technology to a skeptical customer—a system development com-

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[33] Defense Science Board, op. cit., footnote 2, pp. 22-23.

[34] Providing contingency funding in DoD budgeting is discussed later in this chapter under "Reducing Program Variability."

Table 5—Navy Advanced Technology Demonstrations

FY 1987	FY 1988	FY 1989
Advanced Fiber Optic Technology	All-Optical Towed Array	Surveillance IRST (infrared search and track)
SEA RAY (fiber optic tether)	Unified Network Technology	MADOM (magneto-acoustic detection of mines)
Undersea Weapons Technology (heavy torpedo propulsion improvement)	Airborne Transient Processor (signal processor)	Quiet Weapon Launch (undersea heavy-weight weapons)
	Fiber Optic ADCAP (heavyweight torpedo)	Adaptive Monopulse Countermeasures
		Ultra-Low-Noise Crossed Field Amplifier[a]

[a] Added to replace the canceled BRIGHT EYE.

SOURCE: Office of the Secretary of Defense.

mand—without making the customer pay up front. They are not appropriate for high-payoff, but low-risk, projects that users are willing to fund without any additional incentive. If an ATD proves to be successful, according to criteria the user has agreed to in advance, the user agrees to pick up future funding. Even with future user support assured, the new technology cannot be incorporated into new systems unless the industrial contractors providing those systems are involved. Typically, about half the effort on an ATD is performed by industry. Moreover, once an improved technological capability has been demonstrated to the Navy's satisfaction, the Navy will provide incentives for contractors to use it. For example, the Navy may establish performance requirements that cannot be achieved with older technologies.

Sources for Navy ATDs come from Navy and other DoD labs, DARPA, and industry. In 1988, 55 proposals were submitted that were ultimately winnowed down to 7 new starts. Projects take a maximum of 3 years and cost about $12 million each over that time. The total ATD budget is projected to grow to about $65 million per year. In fiscal year 1989, the ATD budget was $32 million, which represented about 17 percent of the total Navy 6.3A budget. However, the Navy is moving towards applying ATD management techniques to a much greater fraction of its 6.3A activities; it is estimated that some 50 to 60 percent of the Navy's 6.3A budget could be managed under the ATD model.

Budgets for individual ATDs are protected unless and until they run into problems. Since the projects selected are all high-risk, technical problems are expected; however, to prevent other projects from being dragged down, projects that get into trouble are killed. For example, BRIGHT EYE, an electronic countermeasure program scheduled to start as an ATD in fiscal year 1989, was terminated when it appeared that it would not be able to meet its technical objectives. Budget cuts are not distributed proportionately to all ATDs, but rather are absorbed by canceling the lowest priority projects in their entirety.

OSD, following up on the DSB 1987 summer study that recommended use of ATTDs, is trying to apply this management technique to 50 percent of the 6.3A programs across the Services.

Air Force—The Aeronautical Systems Division (ASD) of the Air Force Systems Command has institutionalized a technology transition process between the Air Force laboratories, which control much of the Air Force's technology base activities, and SPOs within ASD, which are responsible for developing new systems. The objectives of the new process are to bound and focus activities at the laboratories, and to enhance the involvement of acquisition managers within technology base activities, i.e., to narrow the gap between the originators and users of technology.

When an Air Force laboratory proposes a new 6.3 activity, part of the budget submission process involves preparing a technology transition plan. This plan is presented to a panel composed of representatives from the engineering support directorate (EN) of ASD. This panel—called SENTAR, for Senior EN Technology Assessment Review—evaluates the program's objectives, recommends modifications, compares the program's schedule to its need in the field, helps determine the program's priorities with respect to the lab's other 6.3 work, guides the development of criteria that will denote when the activity is ready to be picked up by a system project office, and determines when the project meets those criteria. A major goal of this process is to identify system project offices—the users—that can benefit from the new development. In doing so, the process generates customers for these innovations who have an interest in seeing them through to completion. Interested program offices commit to a "strong moral obligation" to pick up support for the activity, should it meet the goals identified in its technology transition plan.

This technology transition process also establishes incentives for industry to incorporate new technologies in their bid proposals. The EN of ASD reviews all Requests For Proposals issued by ASD. In these reviews, EN checks to see that the government requester will be receptive to companies bidding technologies that have successfully passed through the SENTAR process. If a company is satisfied that use of a new technology will not be considered too risky by the proposal evaluators, it will be much more likely to incorporate that technology into its bid.

DARPA—The Packard Commission urged that DARPA, which was at the time charged with conducting research and exploratory development in high-risk, high-payoff technologies, also put emphasis on prototyping defense systems. DARPA has since been given an expanded mission in this area. For fiscal year 1989, technology demonstrations were funded at a level of $237 million, or about 42 percent of DARPA's 6.3 budget. Prototype funding was included in the fiscal year 1989 budget within technology demonstrations, and totalled $43 million. For fiscal year 1990, prototyping funds will more than double to $94.7 million and will be separated from demonstrations; the remaining technology demonstrations will be funded at $167 million, $27 million below their fiscal year 1989 level.

Given that the military Services at present largely have control over their own research, development, and acquisition programs, DARPA is perhaps the only agency where a revolutionary new technology that may not fit within the perceived missions of the Services—or that might be seen as threatening those missions—can be explored. However, precisely because DARPA is outside the existing Service acquisition chains, it has in the past faced difficulty in turning technologies over to the military Services for implementation. Giving DARPA a greater role in prototyping will aid the transition of DARPA-sponsored technology from the laboratory to a major field experiment. However, without participation by or interest within the military Services, the problem of turning the technology over to the Services for development into systems might remain.

An additional concern raised over giving DARPA a greater role in prototyping is the degree to which it will retain its original mission of exploring high-risk, basic technology. If the expensive prototype demonstrations siphon funds from these activities, DARPA's original mission could be endangered.

Preplanned Product Improvement and System Upgrades

In addition to the increased use of prototypes and demonstrations, another solution to the problem of attempting too large a technological leap is the concept of preplanned product improvements. If a system is designed from the start with the intention of periodically upgrading its capability, its operators can be assured that they will be able to add state-of-the-art technological capability in the future without demanding it all at once.

Product improvements, or system upgrades, offer a lower-cost and faster alternative to new systems development for getting new technology out into the field. However, since they do provide an alternative, upgrades may be resisted by the Services as posing a threat to new system development. For example, in the past the Navy has been reluctant to propose upgrades to its existing fleet of Los Angeles-class submarines because those upgrades might be seen as reducing the rationale for the Seawolf, a major new submarine that the Navy sees as essential to counter the increased Soviet threat. Moreover, more realistic lifetime estimates for deployed systems are necessary if upgrades to those systems are to receive realistic consideration.

Summary

Technology demonstrations have the potential for solving two seemingly contradictory problems: overemphasis on what later turns out to have been unproven technology, and unwillingness to accept what later turns out to have been viable technology. By convincing the skeptics that a technology can work, and at the same time disabusing the optimists of the notion that it can do everything, objectively evaluated technology demonstrations enhance the technology insertion process.

Prototype development is thought by some to be an important aspect of realistic program planning and cost evaluation. However, others caution that excessive prototyping can impede the very process that it is supposed to enhance.

THE DEFENSE ACQUISITION SYSTEM

Introduction

For years, defense analysts have been frustrated with the length of the acquisition process. Delays in acquisition lead to lost time in fielding new systems, and threaten our technological lead over the Soviets. These delays also result in higher costs due to the expense of maintaining extended development efforts. Even more serious than the increased time and cost, according to a DSB panel[35] that studied the acquisition cycle over a decade ago, are the "second order effects" of delays: technological obsolescence by the time new systems are fielded, increased risk as designers stretch the state of the art to avoid this obsolescence, and added complexity as delays aggravate the tendency to want "everything."

Moreover, delays beget additional delays. Cost escalation due to delays, together with budgetary ceilings, leads to program stretchouts that compound the original delay. Extending the expected time for deployment also causes planners to magnify the anticipated threat, upping the systems' requirements and lengthening the development time still further.

No single aspect of the acquisition process is responsible for schedule delays. To prevent delays, and to shorten the acquisition cycle, the overall acquisition process must be made more efficient and more effective. Therefore, the following discussion of acquisition, along with Appendix A upon which this discussion is based, takes a broad view. It examines several systemic difficulties with acquisition, each of which can lengthen the acquisition cycle or drive up its cost (which, as stated above, can amount to the same thing).

These problems are not new. The foreword to a recent compilation of six major studies of defense acquisition over the past four decades states that "the bulk of the cures proposed as far back as 1948 were still being proposed in 1983 because they had never been implemented."[36] The possibility certainly exists, of course, that none of these studies identified the real problems, which therefore remain to be addressed. Alternatively, perhaps sheer intransigence and bureaucratic inertia within the Department of Defense keep it from substantially improving its operation.

More likely, however, is that many difficulties in defense acquisition stem from factors that are beyond the Department's direct control and that no amount of unilateral DoD activity can address. **To the extent that such external factors dominate, improving defense acquisition will require making large-scale structural and institutional changes that would not be restricted to DoD.**

Some of these changes are impossible within our present system of government. Others would interfere with various objectives that the nation has so far—explicitly or otherwise—decided are at least as important as efficient defense acquisition. And still others involve resolving longstanding political disagreements and identifying common ground in the face of seemingly incompatible positions.

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[35] Defense Science Board, op. cit., footnote 31, pp. 38-39.

[36] David Lockwood, Andrew Mayer, and Cheryl Crow, Library of Congress, Congressional Research Service, "Defense Acquisition: Major U.S. Commission Reports (1949-1988), Vol I," prepared for the Defense Policy Panel and Acquisition Policy Panel of the Committee on Armed Services, House of Representatives, Committee Print No. 26, Nov. 1, 1988, p. V.

Since the constraints within which defense acquisition must operate are so important, the discussion that follows begins with a description of some of these constraints and their effects. Next, the analyses of particular acquisition problems, and specific options that have been proposed for ameliorating some of them, are presented. The chapter then concludes with a more general discussion of four different overall approaches that can be taken towards defense acquisition reform. Depending on which overall approach one selects, different specific options make sense.

Comparison With the Private Sector

One of the most important features of defense acquisition is that it is conducted by the government. Since the premise is widely accepted that the private sector can accomplish tasks more efficiently and cheaply than the bureaucracy-encumbered Federal Government, previous studies have looked to the private sector to provide a model. A 1977 study by the DSB found that, while the portion of the defense acquisition cycle preceding full-scale development had lengthened over the previous two decades, the corresponding interval for commercial aviation programs had not (see Appendix B of Volume 2).[37] More recently, the Packard Commission concluded that "major savings are possible in the development of weapon systems if DoD broadly emulates the acquisition procedures used in outstanding commercial programs."[38]

There are certainly lessons that the private sector can offer the Federal Government, lessons that the Packard Commission sought to uncover. However, fundamental and inherent differences between the government and the private sector must be understood before any of these lessons can be applied.

These differences—described more fully in Appendix A of Volume 2—concern factors such as the inability to measure government effectiveness in the same way that profit, or return on investment, provide figures of merit for the commercial world. They involve the standards of accountability demanded by the taxpayer—and imposed by Congress—on the expenditure of government funds, as well as the pursuit of national goals such as fairness, environmental protection, and equal opportunity that may interfere with the ability to acquire defense systems efficiently.

Other important differences between the government and the private sector include the role of Congress and the political process, which has no parallel in the commercial world. DoD's sheer size (its budget is several times larger than that of the largest U.S. corporation) imposes inefficiencies of scale not shared by smaller private-sector operations. Market forces that reward efficient companies and punish inefficient ones have no counterpart within the DoD, which cannot simply sell off or disband a military Service or agency that does not perform as well as hoped. As James Schlesinger, former Secretary of Defense, has stated;

> This is a society that based its system of government on the Constitution, which calls for a dispersion of powers. That means that everybody has to agree, and under normal circumstances, most people don't agree. As a consequence, we are never going to have the kind of model efficiency in the Department of Defense, or in government generally, that some kind of theorist would want.[39]

Efficiency v. Effectiveness

Defense analyst Edward Luttwak has stated that "The great irony is that the defense establishment is under constant pressure to maximize efficiency, and that its leaders believe in that goal when they ought to be striving for military effectiveness—a condition usually associated with the deliberate acceptance of inefficiency."[40] The nature of defense acquisition imposes specific requirements that go beyond even the disincentives to efficiency facing government activities in general. Much of the technology used in defense systems is at a level of sophistication ahead of that used in the commercial sector—if indeed any commercial analogs exist at all. Although the defense lead is not as pronounced as it has been—and several areas of defense technology now lag behind their commercial counterparts—military technology must nevertheless often be developed from scratch for a relatively limited production run.

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[37] Defense Science Board, op. cit., footnote 31.

[38] President's Blue Ribbon Commission on Defense Management, op. cit., footnote 30, April 1986, p. 12.

[39] "The Second Annual Report of the Secretaries of Defense," edited transcript of a conference held by the Southern Center for International Studies, at Gaillard Municipal Auditorium in Charleston, SC, Sept. 30, 1988, p. 24.

[40] Edward Luttwak, "The Price of Efficiency," *Military Logistics Forum*, July/August 1984, p. 22.

Since DoD is the only customer for sophisticated military systems, producers do not have the option of selling elsewhere should they not be able to sell to DoD.[41] If the Defense Department wants to maintain a diversity of suppliers, it must buy enough from each of them to keep them in business—even if their products may not be DoD's first choice. The most efficient producer of a military system cannot be permitted to drive the others out of business. Aggravating the problem of maintaining a viable production base are annual purchase sizes—typically determined by externally imposed budgetary limits—that mandate suboptimal production rates.[42]

Entrepreneurs in the commercial sector willingly accept the risk of failure—in the form of a loss of investment or reduced earnings—as the price for the chance to strike it rich. Substantial failure on the part of DoD, however, would have consequences that could be far more severe. Therefore, DoD practices a far greater degree of redundancy and risk aversion than a commercial enterprise does. Such risk aversion also extends to proposals for reform, which face a stricter "burden of proof" than might be expected for corporate reform.

In light of the factors that characterize government activities in general and defense acquisition in particular, it may well be true, as defense analyst Leonard Sullivan has concluded, that "many efforts to make acquisition more efficient are simply second-order expedients to paper over largely insoluble first-order problems."[43]

Analysis of the Acquisition Process

The President's Blue Ribbon Commission on Defense Management was not the first attempt to apply lessons from the private sector to defense management. Seventeen years before chairing the Commission, David Packard, then Deputy Secretary of Defense, established the present DoD acquisition process to emulate industrial practices of project management and sequential review and approval. The basic process is one of distinct phases separated by decision points or milestones. OSD develops policy for major system acquisition programs and conducts reviews to ensure that those programs respond to specific needs and are managed soundly. The military Services and defense agencies individually, for the most part, identify those needs and define, develop, and produce systems to meet them.

DoD acquisition programs are run according to the principle of Program Management, in which one individual, the program manager, is responsible for integrating in a single office the diverse administrative, professional, and technical capabilities required to manage the development and production of a major system. However, many people and organizations inside DoD, but outside the program office, have considerable influence over the program's outcome as well. **The separation of responsibility and authority—whereby people with no direct accountability for a program's outcome nevertheless exert control—has been identified by study after study as a major problem of the defense acquisition structure.** Analysts differ as to the degree to which power and accountability can be brought back together in the defense acquisition environment.

The review and oversight that acquisition projects receive at all levels, from commands within individual military Services through OSD to Congress, has also attracted considerable attention from analysts of the acquisition system. Many critics decry what they see as excessive bureaucratic layering and micromanagement. However, others point out—as did the GAO—that such critics "fail to realize that program managers are responsible for expenditures involving billions of dollars in public funds and that a system of checks and balances is essential."[44] The level of scrutiny needed to ensure an appropriate level of checks and balances remains controversial.

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[41] Companies can produce for export, but such exports must be approved by the U.S. Government and are not usually approved for technologies at or above the state of the art available to U.S. forces. Moreover, as the abortive F-20 fighter program demonstrated, foreign governments may not want U.S. systems that the U.S. DoD is unwilling to buy.

[42] In-depth examination of defense industrial base concerns is beyond the scope of this study. For treatment of this subject, see "Bolstering Defense Industrial Competitiveness," Report to the Secretary of Defense by the Under Secretary of Defense for Acquisition, July 1988; and the report of the Defense Science Board 1988 Summer Study on the Industrial Base, 1989. Weapon system production rates are discussed further in *Effects of Weapons Procurement Stretchouts on Costs and Schedules* (Washington, DC: U.S. Congressional Budget Office, 1987).

[43] Leonard Sullivan, Jr., op. cit., footnote 6.

Problems in defense acquisition can be separated into a number of categories, including: program variability (sometimes called program instability); the requirements generation process, including the process by which resources are allocated and weapons systems are selected; bureaucratic paralysis; inappropriate organization of the defense procurement system; and the quality of and incentive structure facing acquisition personnel.

Program Variability

Sources of Program Variability—Perhaps the most significant difference between defense acquisition programs and commercial activities is the degree and the unpredictability of year-to-year change in defense programs. Constant variation makes sound management impossible. As a result, studies of the defense acquisition system always highlight variability as a major problem.

Many pressures for changes in defense acquisition programs are peculiar to government procedure, originating from every level of congressional and executive branch operation. Other stimuli for change, shared by both government and private activities, are changing threats (or market demands, in the commercial world) and the inherent uncertainty of the technology development process. **Even if the changes due to governmental procedure could somehow be eliminated, these latter sources—which no amount of planning or acquisition reform can remove—would remain.**

A key source of self-imposed change is politics, not in the pejorative sense that the word has acquired connoting back-room deals, influence peddling, and pork barrelling, but in its original definition as a struggle between competing interests. Decisions to build multi-billion dollar weapon systems do not merely follow from technical or strategic analyses. They also represent choices concerning the relative importance of certain military needs over others, and of those military needs over other public needs (e.g., housing, health care, economic security, tax relief, and deficit reduction). Finally, these decisions also ultimately represent commitments to specific manufacturers employing people and purchasing goods in specific congressional districts. These are inherently political decisions, and in the United States, no political decision is final.

The political process involves constant competition and interaction among many different actors: the military Services against one another and against OSD, DoD against the rest of the executive branch, the executive branch against the Congress, and various committees, subcommittees, and Members of Congress against one another. When the interests of many of these parties align, differences between them can be resolved. However, in the face of fundamental disagreement, the competition for influence and control can make it very difficult to maintain continuity.

The struggle between Congress and the executive branch leads to what is generally referred to as "legislative oversight responsibilities" within Congress and as "micromanagement" within the executive branch. It results in hundreds of budget line item changes and other legislative restrictions and requirements each year. Although congressional modifications to the DoD budget request certainly complicate program management, changes generated within the many layers of DoD management add significantly to the problem. Many, if not most, of the budget cuts imposed upon or generated within DoD are due to DoD's inability to forecast program costs accurately, to defer new starts until sufficient funding to cover the actual (rather than the originally estimated) costs is available, or to eliminate programs—rather than stretch them out—in the event of funding shortfalls. GAO has found that, although the impact of underfunding programs is "well-recognized and documented, a workable and effective method for matching DoD's needs with budgetary constraints has not been developed."[45]

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[44] U.S. General Accounting Office, "A Critique of the Performance of the Defense Systems Acquisition Review Council: Billions in Public Funds Involved," PSAD-78-14, Jan. 30, 1978, p. i.

Reducing Program Variability—Although measures can be taken by both Congress and DoD to reduce the number and effects of program changes, changes cannot be eliminated. Analysts disagree as to which of two management failures is the more serious in the light of unexpected change: failure to plan and budget flexibly, or failure to hold to a fixed schedule. Efforts to reduce program variability include reforming congressional budget review procedures, multiyear budgeting, program "baselining," increasing DoD management flexibility, and reducing personnel turnover.

Reforming the Congressional Budget Review Procedure—The current congressional budget process, involving three levels of review between the budget committees, the authorizing committees, and the appropriations committees, takes too long to complete. Final decisions on the defense budget are made by congressional conference committees as (or in many recent cases, after) the new fiscal year starts, late in the executive branch's preparation of the following fiscal year's budget. Last-minute changes in the appropriated funding levels require last-minute changes to the next year's request—changes that can be difficult to accommodate in a rational manner.

Changing the congressional budget process would require a major revision in congressional procedures that would involve either cutting down the number of committees having a significant role or sharply delineating committee responsibilities. However, Congress is a highly pluralistic institution, and there is no single individual or organization that can mandate these changes. Enacting them would therefore require either widespread agreement within Congress or the unilateral abdication of authority on the part of committees that are now involved.

Even if the number of actors reviewing the budget is reduced, the structure of that budget may not be optimally suited for evaluating defense roles and missions. Congressional review of the defense budget now deals more with accounting inputs (dollars, personnel slots, buildings, etc.) than with defense outputs (mission capabilities or strategic goals). The inputs are easier to count and to control, and unlike defense mission capabilities they permit comparisons to other programs across the entire Federal Government. However, they also focus congressional attention on funding for individual program elements, whereas many argue that a more appropriate role for Congress would be a high-level strategic review.

Multiyear Budgeting—Lengthening the budget cycle would provide a longer planning horizon and require less frequent congressional review. Congressional oversight would be directed more towards strategic guidance and away from individual line items, offering the hope that programs could enjoy greater stability. Although there are constitutional restrictions on appropriations longer than 2 years for certain military purposes, legislative and executive procedures could be changed to permit budgeting in 2-year intervals, and program authorizations could be even longer-term. However, this approach has limits, because absolute program stability is fundamentally incompatible with holding elected officials accountable at periodic intervals for their actions. Every time an elected official is replaced, there is—and must be—the opportunity for the new official to change the way things have been done.

Although biennial budgeting was attempted for DoD for fiscal years 1988 and 1989, no funds were appropriated for 1989 during the 1988 budget cycle. One effect that the experiment did have, however, was to give Congress more visibility into out-year plans of DoD than it had previously had. In particular, for the 1990-1991 budget submission, Congress will for the first time be given access to DoD's Five Year Defense Plan. Although some might fear that this visibility would simply give Congress that much more opportunity to meddle, it is also plausible that improving the communication between Congress and DoD in this manner can help give Congress the confidence in DoD planning that is needed before Congress can relax its level of oversight and micromanagement. It extends the planning horizon, enabling both Congress and DoD to take a longer view.

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[45] U.S. General Accounting Office, "Major Acquisitions: Summary of Recurring Problems and Systemic Issues 1960-1987," GAO/NSIAD-88-135BR, September 1988, p. 10. (See also the previous section of this chapter on "Affordability.")

Baselining—A "baseline" is an internal contract between a military program manager and the senior management of his or her Service concerning the cost, schedule, and performance milestones for a new weapon system program. Since changes to the baseline require equally high level review, formalizing a baseline represents an attempt to reduce the amount of change that programs undergo within DoD. In practice, however, baselining requires that the program manager have the authority to reject changes to his or her program that are imposed from sources outside the program. Granting this degree of authority is extremely difficult within the present DoD environment. For example, although specified in a program's baseline, one of the most important program parameters, its budget, is in the final analysis established externally. Moreover, it is often changed annually by the Congress. Fully realizing the benefits of program baselining requires extending it, or some equivalent, to Congress. It also requires providing program managers or their superiors sufficient authority to resist or accommodate changes imposed by other DoD organizations, such as testing and evaluation offices. Changes of this scope would go against recent congressional initiatives that strengthen independent auditing and evaluation functions within DoD.

Increasing Management Flexibility—Another way to reduce the variability of DoD programs is to increase the Defense Department's ability to adjust to changing circumstances without requesting congressional approval. DoD's ability to accommodate changes—whether imposed by Congress or resulting from changing threats or unanticipated technological difficulties—is also limited by the absence of reserve funds. Unless a means is available for addressing unforeseen problems quickly, it is often impossible to meet expected costs and maintain schedules.

Although no individual program's requirement for such reserves can be predicted, the amount likely to be needed by a group of programs can be statistically estimated in aggregate. However, the intense competition for funds within DoD and the degree of scrutiny applied to defense budgets by Congress both mitigate against providing reserves. Indeed, in an environment where there are already far more claims on defense dollars than there are available funds, there is every incentive to underestimate the costs of programs when Service budgets are prepared. So even if contingency reserves are initially provided for, they are one of the first items to be trimmed. And were management reserves somehow to survive DoD's internal budget preparation process, they would probably not fare well on Capitol Hill, where they—referred to as "slush funds"—are usually eliminated to protect the taxpayer from waste, fraud, and abuse.

Members of Congress, on the other hand, can point to instances where they believe DoD has used internal fund transfers to evade congressional restriction or to protect programs that Congress has sought to delay or cancel. Providing DoD with management reserves and raising the thresholds for internal funding transfers will therefore require establishing a relationship of greater credibility and trust between DoD and Congress.

Personnel Turnover—Another contributor to program variability is turnover in acquisition personnel. Although typical defense programs have lifetimes measured in decades, the average tenure of defense program managers surveyed by GAO in 1986 was less than $2^{1}/_{2}$ years. Such short tenures make it difficult to increase the authority of program managers, because they hinder any attempt to assign accountability. Moreover, short tenures can generate pressures to sacrifice long-term quality for short-term results. (See the section on "Acquisition Personnel" below.)

Requirements Generation and Resource Allocation

Weapons systems are procured by "buying commands" within the military Services that are not directly tied to the Commanders in Chief (CINCs) of the operational forces, who (or, more often, whose successors) would have to use those systems in combat.[46] As a result, many studies have found that, the operational users are not sufficiently involved in the acquisition process, including the establishment of the military requirements that initiate new acquisition programs. Furthermore, requirements, when established, tend to be observed rigidly rather than being reexamined in light of new circumstances such as schedule and cost overruns. While changing the requirements too frequently does exacerbate program variability, as described above, unwillingness to make changes in light of changing circumstances can force cost, schedule, and complexity upwards.

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[46] For operational purposes, the Armed Forces are organized into military commands that report through the Chairman of the Joint Chiefs of Staff and the Secretary of Defense to the President. The military Services themselves, each headed by a civilian Secretary, are responsible for training and equipping military forces, but not for commanding them operationally.

Requirements tend to be overstated due to insufficient interaction between those who know what is needed and those who know how to provide it. Further pressure for exaggerating military requirements stems from the process by which DoD decides to develop new systems. This process is conducted essentially in two stages. Once a military requirement has been established, funds to meet that requirement must be found in a highly competitive and political environment involving the military Service, OSD, the Office of Management and Budget, and Congress. After funds are reserved, a second stage of competition selects the actual supplier.

The funding competition imposes great pressure to over promise capability while underestimating cost; there are few incentives to enforce realism. Specific designs cannot be offered at this stage because they would interfere with the ensuing source selection competition. Program managers, who should be in the best position to weigh the military requirements for a system against the technological prospects for satisfying those requirements, are generally brought into the acquisition process too late to have a significant impact on requirements generation. It also appears that they are too seldom able to modify requirements in response to subsequent events.

A recent study aimed at monitoring the reorganization of DoD, which drew upon the Packard Commission's recommendations and the Goldwater-Nichols Defense Reorganization Act, noted progress in enabling trade-offs to be made between requirements, cost, and schedule and in taking affordability more seriously. "The organizations and procedures that could make possible such a change [in acquisition procedures] have been set up," the study concluded, but "their effective operation will require continued high-level attention."[47]

Bureaucratic Paralysis

Causes and Effects**—**A constant complaint of those involved throughout the defense acquisition process concerns the increasing bureaucratic burden they must struggle through in order to do their jobs. This bureaucracy manifests itself in multiple levels of approval, the diffusion of responsibility and authority, the lack of individual accountability, and the profusion of auditors, inspectors, specifications, and regulations. It is blamed for causing excessive delay, stifling innovation, suppressing initiative, and increasing costs.

Although these perceptions are widespread, they are difficult to validate objectively. Analysis attempting to quantify trends in regulatory activity found some indicators that showed increases and others that did not. The effects of governmental bureaucracy and regulation are even harder to measure than the trends in regulatory activity, given the absence of a standard for comparison. Although private sector activities are often held out as models for defense acquisition, it is not clear how relevant they are to government operations (see sections on "Comparison With the Private Sector" and "Efficiency v. Effectiveness" above). Therefore, the usefulness of studies measuring how much lengthier or more expensive government programs are than "equivalent" private sector ones is limited. Given all the uncertainties and difficulties of estimating the cost penalty imposed on defense acquisition by existing defense acquisition regulations, it is not surprising that such estimates are widely divergent. They range from a few percent to more than 50 percent.

A simple model of the cost of excessive regulation is shown in figure 9. With minimal regulation or oversight, the government is dependent upon the goodwill of contractors and public officials. Honest officials and corporations could operate very efficiently in this regime, but dishonest ones would take advantage of the lack of oversight to defraud the government. At the other end of the spectrum, tight regulatory controls deter or detect those defrauding the government, but they also drive up the cost of doing business for everyone else.

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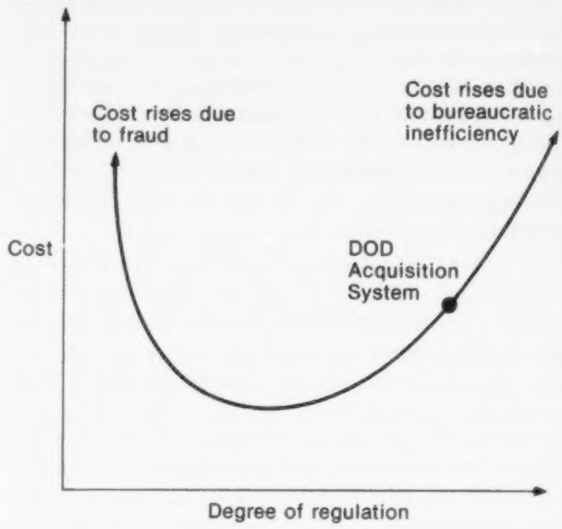
[47] Harold Brown and James Schlesinger, co-chairmen, "Making Defense Reform Work: The Project on Monitoring Defense Reorganization," a joint project of the Johns Hopkins Foreign Policy Institute and the Center for Strategic and International Studies, Washington DC, November 1988, p. 49.

Much of the political debate concerning "waste, fraud, and abuse" concerns where on this curve the defense procurement system lies. Analyses of defense procurement consistently indicate that the system lies somewhere on the side of excessive regulation, at least in terms of strictly economic considerations. However, the public—to which Congress responds very effectively—may well believe that the system is not yet regulated enough, especially in the wake of recent reports of procurement scandals and defense contractor fraud. It may be that the costs of imposing stricter controls are not well understood by the public, and that if these costs were more widely recognized, calls for additional regulation would be moderated. However, it is also conceivable that the American taxpayer prefers to pay the high costs of overregulation rather than permit even lesser amounts of public money to go unearned into someone's pocket. If public demands for overregulation can be thought of as a source of avoidable waste, then perhaps some waste must be considered the price of curbing fraud and abuse.

Some argue that the present approach of legislating strict oversight and accountability requirements has the effect of penalizing everyone in defense acquisition instead of just those individuals who are truly guilty of violations of ethics or law. One alternative system, according to this line of reasoning, would be one in which people are trusted to be capable of doing their jobs without intrusive oversight and indeed are allowed to do so. However, those found guilty of violating this trust would be punished severely. While the relaxed oversight might reduce the probability of detecting illegal or unethical activities, those actions could nevertheless be deterred by the increased severity of the punishment if caught. This approach would replace the current adversarial relationship between government and industry with a more collaborative one.

Reducing Paperwork and Bureaucracy— Measures to cut red tape or streamline the bureaucracy will fail unless they take into account the reasons why the bureaucracy was initially established. Regulations and guidelines are a means of preserving institutional memory in an environment where presidential appointees have a median length of service of just over 2 years[48] and where military personnel are regularly rotated. They incorporate the political oversight and review procedures that come with the expenditure of public funds. They codify management procedures for large and unwieldy organizations. **Finally, regulations and guidelines further important policy objectives that may be in the nation's or DoD's collective best interest even though they might interfere with the most efficient execution of individual programs.** As has been stated before, the government has many goals—environmental protection, occupational health and safety, fair labor practices, equal opportunity, etc.—that may conflict with any individual program manager's ability to run a program efficiently. Just because a program manager does not believe his or her program should be the vehicle to implement national policy does not mean that that policy should be ignored. Although regulations have

Figure 9—Cost v. Regulatory Intensity



SOURCE: Office of Technology Assessment, 1989.

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[48] National Academy of Public Administration, "Leadership in Jeopardy," November 1985, p. 4. (This figure applies to the entire Federal Government.)

been criticized as attempts to solve yesterday's problems by impeding today's progress, those problems are certain to reappear in the absence of some means of institutionalizing the lessons learned. **In other words, much of the bureaucracy and regulation surrounding defense acquisition has resulted from the political environment—reflected in public opinion and in legislation—within which defense acquisition is done.**

Studies such as that of the Packard Commission have recommended changes in the DoD bureaucracy that would have the effect of delegating authority to lower levels. Program managers and their immediate superiors would be freer to do their jobs, and the advocates for interests such as competition, small business, equal opportunity, testing and evaluation, etc., would be relegated to advisory roles. In particular, the Packard Commission recommended setting up a streamlined acquisition chain of command in which program managers would report through no more than two levels of command to the senior procurement executive in DoD (the Under Secretary for Acquisition). Much of this structure has now been established. **However, the new structure supplements—and does not replace—the existing chains of authority and command.** According to the study monitoring implementation of the Packard Commission recommendations:

> . . . the purposes of the legislation [implementing some of the recommendations] have not been met. Our sense is that the new positions were simply superimposed on top of the existing structure.[49]

The new acquisition chain is at present a communications link, and does not control funds. Truly implementing the Packard Commission's recommendations would require substantial changes in the operation of DoD.

The Packard Commission and other studies held out certain programs within DoD—in particular, highly classified "special access" or "black" programs[50] and high-priority strategic programs—as models that have successfully conquered the DoD bureaucracy. Special access programs, due to extreme security requirements, bypass much of the review, approval, and bureaucracy that ordinary programs must contend with. However, those same security constraints make these programs difficult to analyze in general.

Some officials with extensive experience in both special access and ordinary program management say that the approaches used in the special access world enable equipment to be fielded much more quickly, and at lower cost, than do standard acquisition programs. Other officials say that the high priority, high-level review, and high-quality staffs of special access programs, more than their management techniques, are responsible for their success. Moreover, they point out that bypassing checks and reviews—although sometimes necessary in the name of security—adds considerable risk. While some say that extension of special access contracting procedures would improve acquisition, others say it could not provide a general solution.

A number of different approaches can be taken to reduce bureaucracy and regulation within DoD. Implementing any of them, however, presumes an atmosphere of trust among DoD, the rest of the executive branch, and Congress; many reforms require the same degree of trust to hold between DoD and the defense industry.

Major Legislative and Administrative Reform—One approach would be to replace the existing statutory and administrative framework, in which fraud and abuse are deterred by extensive reporting and auditing requirements, with one in which greater responsibility is placed on voluntary compliance coupled with vigorous enforcement and severe punishment for those who get caught breaking a law. Enacting such a system would involve a major overhaul of the existing defense acquisition system and the environment in which it operates. Moreover, it would require (and also follow from) reducing what many in government and industry see as the existing adversarial relationship between the two.

Bottom-Up Review—The opposite approach is to start with the present system but examine each regulation, directive, and specification to ensure that it is still relevant and appropriate. Such a task would be a mammoth undertaking. Moreover, those with the time to review the regulations would most likely not be the ones adversely affected by them, and it is unlikely that this approach would effect significant change.

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[49] "Making Defense Reform Work: The Project on Monitoring Defense Reorganization," op. cit., footnote 47, p. 50.

[50] Technically, DoD does not use the term "black" program. A "special access program" is one in which additional restrictions beyond those available through the normal Confidential-Secret-Top Secret classification system are deemed required. The budgets and existence of such programs may or may not be classified. "Black" programs generally refer to those whose existence is kept secret.

Evolutionary Review—Another approach, which is being implemented in a number of DoD activities, is to establish a mechanism by which those adversely affected by a regulation can petition for its waiver, with all such petitions examined to see which regulations should be waived or modified across the board.

Those affected by a regulation can already seek its waiver from the issuing authority without any special program. However, DoD programs such as the Pilot Contracting Activities Program and the Model Installations Program have been established to provide waivers in a more systematic way. Requests for waivers are tabulated to identify those regulations that seem to provide the greatest barriers. If approved, waivers are evaluated on an experimental basis to see if they should be made permanent or even extended DoD-wide. These programs at present cannot waive regulations imposed externally on DoD (by legislation, for example). However, they can identify those external regulations and laws that participants find to be particularly onerous, and the DoD can then propose legislation or regulatory reform at higher levels to ameliorate the problem.

One drawback to this approach, from the point of view of those seeking major reform, is that it is an evolutionary process. Another problem is that in at least some cases, individuals having to put up with obsolete, ineffective, or inapplicable regulations have found it far easier to ignore them than to petition for their waiver.

Shifting the "Burden of Proof"—In this approach, the "burden of proof" is shifted from those seeking to waive regulations to those seeking to enforce them against the objections of the program manager. Essentially, it consists of pre-delegating waiver authority all the way down to the program manager, who could decide which regulations are appropriate. The "special interests" and "advocates" would still exist and would still be free to make recommendations to the program manager. However, the program manager would be free to disregard their advice, unless they were able to persuade the program manager's superiors. To the extent that regulations are simply being ignored today, as described in the preceding paragraph, this approach is in essence being taken now—without official sanction.

Such a system could only work if program managers and their superiors were evaluated not only on how well individual programs fared but also on how well the programs, on balance, supported the intent of the regulations—which, after all, serve to incorporate DoD and national policies that senior policymakers have decided are important. Program managers would have to realize that their goal is not simply development and deployment of a weapon system but furthering national policy as well.

True implementation of this approach would also require congressional action to relax statutory constraints, since those could not be waived by program managers. Moreover, the problem of identifying the essential core of laws and regulations that would remain mandatory—ineligible for waiver at the program manager's discretion—re-creates the original problem. If it were easy to identify the irreducible core of regulations and laws in the first place, this approach would not be necessary.

Organization of the Defense Acquisition System

So far this chapter has discussed acquisition procedures within the existing organization, in which OSD establishes policy and participates in milestone reviews for major programs, but acquisition is executed (and for programs other than the major ones, reviewed) by the Services. However, there are other organizational models, ranging from giving the USD(A) the acquisition authority that presently rests within the Services all the way to creating a civilian acquisition agency outside DoD.

Most studies of defense acquisition argue that the military Services must have primary responsibility for acquisition to ensure that the needs of the operational user are met. However, some civilian analysts argue that much of what goes on in managing acquisition programs does not require, and may not even be greatly aided by, military control. They argue that the professional, stable, and highly trained acquisition work force needed to implement procurement reform can be created only in the context of a civilian acquisition agency. Even so, few proponents of a civilian agency call for it to be outside DoD; most believe that the Secretary of Defense must be responsible for national resources devoted to defense.

Although a study of European nations that use centralized procurement systems might illuminate the successes or failures of such a plan, there are significant factors that make such an analysis difficult. One important difference is that European defense programs are small compared to that of the United States. There are other differences, too: European military services do not dominate acquisition, European defense plans are done on a multiyear basis, the legislatures make minimal changes to annual defense procurement budgets, the government imposes minimal "how-to" requirements on the defense industry, and industrial policy is a major consideration in defense contracting.

One compromise position, adopted by the study group that examined the implementation of the Packard Commission recommendations, would be to encourage each of the Services to create a specialized "acquisition corps," but to consider creating an independent acquisition organization under the USD(A) in the event that the Services balk.[51] Although the study stated a preference for leaving acquisition authority with the Services, it went on to conclude that "radical steps, such as the establishment of a single procurement organization within the Department, should not permanently be ruled out."[52]

Acquisition Personnel

Improving defense acquisition depends on a high-quality, stable, and well-trained acquisition workforce. In a letter to President Reagan one year after the publication of the Packard Commission report, David Packard stated that:

> Personnel policy is the keystone of virtually all of these reforms. With able people operating them, even second-rate organizational structures and procedures can be made to work; and without able people, even first-rate ones will fail.[53]

Improvements recommended by the Packard Commission included reducing the barriers to recruiting senior-level executive branch personnel,[54] attracting qualified new personnel and improving the training and motivation of existing personnel at the middle management levels, and continuing the recent improvements in defining military career paths in acquisition. Members of the Commission thought that civilian acquisition personnel needed much more attention than military personnel, and their report cited many of the deficiencies of the federal Civil Service system that are described in the context of national laboratory personnel in chapter 5.

As was noted in the previous section, the "Project on Monitoring Defense Reorganization" recommended establishing within each of the military Services a professional "acquisition corps." Within these corps, military officers who wished to specialize in acquisition would be able to pursue a career path that did not constantly rotate them out of acquisition billets. They would also receive the training necessary to do their jobs and compensation comparable to their private sector peers. Officers with operational experience would still be assigned to acquisition jobs, but in fewer numbers than now. Although the Services have long resisted establishing such corps, the study concluded that the increased professionalism that this approach would bring is essential for effective and efficient acquisition.[55]

All proposals for reforming acquisition personnel policy run into conflicts among competing objectives. Creating a military acquisition corps could improve acquisition but it would also create a military career path unlike any that the Services now believe to be appropriate. Making fundamental reforms to Civil Service procedures—or even exempting significant groups from them—would pose substantial political difficulties. Federal employees already feel as if they have 240 million supervisors, and it sometimes appears, at least while reading "Letters to the Editor" columns whenever civilian pay raises are debated in Congress, that there is nothing so despised as a civil servant. Proposals that would increase compensation or other benefits of Federal employment in an effort to attract more senior and more highly qualified employees would be seen by many as adding slots to the Federal trough.

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[51] "Making Defense Reform Work: The Project on Monitoring Defense Reorganization," op. cit., footnote 47, p. 59.

[52] Ibid., p. 51.

[53] David Packard, letter to the President of the United States, July 10, 1987; cited by J. Ronald Fox and James L. Field, *The Defense Management Challenge: Weapons Acquisition* (Boston, MA: Harvard Business School Press, 1988), p. 315.

[54] Among the changes specified were simplifying financial disclosure forms and allowing appointees to defer capital gains tax liability incurred in divesting assets so as to satisfy conflict-of-interest provisions.

[55] "Making Defense Reform Work: The Project on Monitoring Defense Reorganization," op. cit., footnote 47, p. 59.

Conflict-of-interest regulations provide a case in point. Many individuals with experience in defense acquisition argue that "revolving door" legislation that erects barriers to the interchange of individuals between government and industry prevents skilled individuals with hands-on technical or managerial experience in the industrial world from contributing their skills to DoD. On the other hand, a significant segment of public opinion—shared by a significant segment of Congress—sees the interchange of individuals between government and industry as providing inherent conflicts of interest. The political reconciliation of these two points of view will be difficult.

Policy Options

Trade-offs, inefficiencies and problems in the defense acquisition system stem from a wide variety of interrelated causes. Some of them are due to structural limitations of the United States Constitution and our resulting political system. Others result from the relationship between the Congress and DoD, and would be amenable to congressional action or clarification. Many problems arise from conscious choices that have been made to emphasize some national goals over others, choices that could be reversed if the political mood of the nation were to shift. And still others are unintended consequences of aggregating many individual actions, each of which may be widely accepted.

Solutions almost always involve trade-offs. Should the government relax its controls over industrial performance, or should they be strengthened? One point of view is that of the Packard Commission, which believed that although major improvements were essential, "self-governance is the most promising mechanism to foster improved contract compliance."[56] Quite a different viewpoint is provided by the Project on Military Procurement, which argued that "as expensive as it is to hire legions of auditors, it is even more expensive to allow contractors to continue to steal and goof off."[57] Although this picture of contractor behavior is not supported by analyses of defense procurement—which generally find that fraud, while certainly present to some extent, does not consume a significant fraction of the defense budget—it does represent the attitude of a substantial fraction of taxpayers and therefore of Congress.[58] Regardless of its merit, reformers of the defense acquisition system ignore this public sentiment at their peril.

Has the overhead that comes with government procurement (viz., accountability trails and socioeconomic goals) impeded defense procurement so badly that we should be willing to trade off these goals to obtain a more efficient system? Is the risk of a visible and, in hindsight, preventable failure worse than the risk of quashing individual initiative by imposing regulations? Are we willing to assign individual accountability and responsibility, knowing that the price of allowing star performers to excel is the risk that incompetent and even criminal actions may take place as well? What are the costs of delaying a military capability v. the benefits of delaying an expenditure? These are difficult but crucial questions.

Incentives

The best, and possibly the only, solutions to acquisition problems involve changing the incentive structure facing people and organizations, rather than imposing additional regulations. The present, acquisition system offers incentives, according to J. Ronald Fox and James Fields, but these often act the wrong way. They argue that no lasting improvement is likely unless an appropriate system of incentives and disincentives is formulated and enforced:

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[56] President's Blue Ribbon Commission on Defense Management, op. cit., footnote 15, p. 84.

[57] Dina Rasor, et al. *Defense Procurement Papers: Campaign '88* (Washington, DC: Project on Military Procurement, September 1988), p. 45.

[58] A public opinion survey of 1,500 Americans taken for the Packard Commission found that the public believes $45 of each $100 in the defense budget goes to waste (poor management) and fraud (illegal activities), with that $45 about evenly split between the two. Money lost through waste and fraud is thought to end up primarily in defense contractors and individuals' pockets. See Appendix L, "U.S. National Survey: Public Attitudes on Defense Management," prepared by Market Opinion Research; in *A Quest for Excellence: Appendix*, Final Report by the President's Blue Ribbon Commission on Defense Management. Executive Office of the White House, Washington, DC, June 1986, pp. 217, 219.

> Unless changes are made in the contractor source selection process, which makes optimistically low cost estimates a significant advantage in competing for a contract, it is useless to discuss realistic contractor proposals. The source selection process must give far more weight to realistic cost estimates and the contractor's record of past performance.
>
> Unless changes are made in the current profit system that demands higher costs as a prerequisite for higher profits, it is futile to expect lower costs. Because profits are largely based on cost, there is little economic motivation for contractors to reduce direct or indirect costs. The profit system needs a major overhaul to relate profits more to contract performance than to the level of costs.
>
> Unless changes are made in the current military personnel system that makes short-term assignments necessary for military officers to acquire the number and variety of assignments required for promotion, any significant reduction in personnel turnover in defense program offices is unlikely.
>
> Unless changes are made in the current OSD and congressional practice of routinely accepting program stretch-outs as a tactic for funding new programs, it is unrealistic to advocate economical production rates.
>
> Unless changes are made in the current DoD practice of waiving training requirements and offering only short training courses, which limit coverage to introductory rather than in-depth treatment of important subjects, it is unrealistic to expect improved training for acquisition managers.
>
> Unless changes are made in military careers that currently provide few opportunities beyond age 45 or 50, it is unrealistic to expect military officers not to seek a second career in the defense industry. In addressing this problem, DoD needs to listen to lieutenant colonels and colonels and Navy commanders and captains to learn their views on the advantages and disadvantages of the acquisition career field.
>
> Without genuine promotion opportunities for those who make the difficult decisions associated with successful negotiating and wise buying, it is unrealistic to expect to retain in government service experienced program managers able to do much more than promote their programs, prepare progress reports, and conduct briefings.[59]

Approaches

Although there are innumerable specific changes that could be made to the way defense acquisition is done, the discussion in this chapter suggests that many policy choices concerning defense acquisition fundamentally rest on where the balance is established between efficient defense acquisition, on the one hand, and furthering national goals such as fairness and accountability, on the other. Four alternate approaches, each establishing this balance in a different way, are presented below. In Approach 1, the balance is tilted sharply towards efficient acquisition. Approach 2 has the same objectives as Approach 1 but pursues them in a more gradual manner. Approach 3, ratifies the present choice of that balance, and Approach 4 takes the position that non-defense-related national objectives should be emphasized even more than they are today.

Approach 1: Enact major structural and legislative reforms of the environment within which defense acquisition takes place, emphasizing efficient procurement over other national goals.

Selecting this approach would represent a conclusion that the existing procurement system places too much emphasis on non-procurement-related objectives. Many laws and regulations mandating, for example, procedures for competitive bid solicitation and award, barriers to conflict of interest, and the promotion of minority-owned and small business, would have to be reviewed and revised to give individual contracting officers and program managers greater authority to do as they see fit for the good of their programs. They would be less involved with justifying every action, establishing audit trails, complying with accounting standards, and fostering full and open competition. Instead, the system would rely more on individual responsibility, which would have to be measured both by the success of the programs and by the necessarily subjective evaluation of their manager's superiors as to how well they protected the public trust.[60] Careful study would be needed to arrive at a new balance between acquisition and these other goals. Successful accomplishment of this approach would also require some degree of societal consensus, and the continuing cooperation of Congress, so that the balance between procurement and these other goals would not be reexamined every budget cycle.

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[59] J. Ronald Fox and James L. Field, op. cit., footnote 53, pp. 318-319.

Approach 2: Preserve the basic structure of the defense acquisition system, but pursue evolutionary changes that would emphasize efficient acquisition over other goals.

This approach is similar in underlying intent to the preceding one, but would not try to do everything at once. To the extent that individual regulations, laws, policies, or procedures could be shown to impede acquisition efficiency, the regulation, law, etc., could be individually evaluated to see what would be lost if it were changed. By proceeding at a much more measured pace than the previous approach, some would argue that it has a much better chance of being implemented and would pose less risk. On the other hand, those totally dissatisfied with the present acquisition system would probably find anything less than a total overhaul insufficient.

Approach 3: Decide that the current balance between efficient acquisition and other national goals is more or less appropriate, and in so doing recognize that acquisition will not be as efficient or as effective as it would be if it were conducted in isolation from those other goals.

This approach, too, would seek evolutionary improvement to the acquisition system when specific impediments could be identified. However, it would not presume that, given a conflict between acquisition and other values, acquisition should necessarily win. Selecting this approach essentially codifies the *status quo*—it would be assumed that the environment surrounding the acquisition process is shaped by a compromise between competing interests and has led to the creation of a system that perhaps pleases no one, but is preferable to any significant alternative.

Approach 4: Extend regulation and oversight of the defense acquisition system under the premise that it is not yet sufficiently responsive to national needs.

Those who see recent press accounts of procurement improprieties and contractor fraud as indicating a lack of supervision and oversight would recommend an approach diametrically opposed to those discussed above. Instead of favoring acquisition efficiency over other objectives, they would seek changes—such as more stringent accounting requirements and conflict-of-interest standards—that would have the effect of increasing the bureaucratic overhead of the acquisition process. Proponents of this approach argue that more stringent regulation would save taxpayers funds on net—i.e., that although the extra controls might cost money to establish, they would prevent an even greater amount of fraud and abuse, or that the price of the further standards is worth paying to ensure public confidence in the acquisition process.

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[60] This latter criterion is not easy to measure. Is it good enough for a contracting officer to consistently award contracts to companies who do good work? What if he or she then retires to take a high-paying job with one of the companies that he or she had favored? What if another company, which had reason to believe that it could have done a job better or cheaper or both, was not allowed to bid? In both these cases, the appearance that the most efficient use of taxpayer funds may not have been made must be considered, even if the reality is that the product obtained was as good as any.

Chapter 9

Civilian Technology and Military Security

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Chapter 9

Civilian Technology and Military Security

MILITARY ACCESS TO CIVILIAN TECHNOLOGY

This assessment was prompted by a concern on the part of the Congress that the defense technology base might be eroding in the United States. As a result, the Armed Services might be unable to retain a technological advantage over the Soviet Union and other possible adversaries in the future. This concern is closely related to two observations. First, certain high-technology industries—such as semiconductors and numerically controlled machine tools—have lost domestic market share to foreign competition. Some appear to have entered a cycle of decreased capitalization, weakened innovation, further loss of market share, and eventual loss of leading-edge capabilities, in both design and process technologies. As a result, U.S. military dependence on foreign civilian technology is increasing. The second observation is that the U.S. military appears less and less able to acquire the leading-edge technology that does exist. Such technologies may be available in the civilian sector of the domestic economy, but they are somehow beyond the reach of the Department of Defense (DoD).

Because of these concerns, OTA conducted policy-oriented case studies of three dual-use[1] technologies—fiber optics, software, and advanced polymer matrix composites (PMCs)—to assess the availability of civilian technology for military purposes and to analyze difficulties in the transition of technology between the civilian and military sectors of the U.S. economy. The case studies avoid extended technical description in favor of policy-relevant analysis of major issues confronting these high technology industries. For each case, the inquiry has addressed three central questions: **1) Are civilian high-technology industries (those critical to the military) eroding in the United States? 2) Do military technologies and their applications diverge significantly from their counterparts in the civilian sector of the economy? 3) What are the principal barriers, both technical and institutional, that inhibit military access to civilian technology and vice versa?** Each of these questions requires some amplification.

The rationale for the first question depends on the extent and nature of military dependence on civilian technology, both domestic and foreign. If it is possible and desirable for the defense industrial sector to develop and produce all technologies necessary for the Services, then the competitiveness of the civilian sector of the economy, while important for other reasons, would not be related to national security considerations. But if the defense industrial sector relies to any substantial extent on research and development (R&D), innovation, and production conducted in the civilian sector, then loss of commercial competitiveness in industries that develop technologies that are pervasive or enabling for military systems would have serious policy implications. A recent report on defense industrial competitiveness by the Under Secretary of Defense for Acquisition took this position.[2] It was also the primary concern of the Defense Science Board (DSB) when it recommended an industrial policy, which amounted to a strategy for economic defense of the domestic semiconductor industry.[3] In the case of semiconductors, the DSB argued in its report that eroding domestic capacity seriously jeopardizes our ability to build and field major weapons systems—unless the United States is willing to depend on foreign firms for strategically important technologies, materials, and devices in the future.

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[1] In this chapter the term "dual-use" refers to technologies that can have multiple, significant applications to military systems, and that can be employed extensively in civilian industry as well.

[2] "As a nation and as a continent, we no longer are totally self-sufficient in all essential materials or industries required to maintain a strong national defense . . . . Clearly, the Department of Defense cannot provide massive financial assistance for every American industry characterized by a lack of international competitiveness, nor can we effectively provide incentives for every manufacturing industry critical to our defense." (Department of Defense, "Bolstering Defense Industrial Competitiveness," Report to the Secretary of Defense by the Under Secretary of Defense for Acquisition, July 1988, p. v.)

[3] Defense Science Board, "Report of the Defense Science Board Task Force on Defense Semiconductor Dependency," prepared for the Office of the Under Secretary of Defense for Acquisition, February 1987.

These concerns have equally significant implications for emerging and fast-moving, high-technology industries such as fiber optics, software, and advanced composites. There is substantial evidence and widespread agreement among experts, for example, that the Japanese government and industry are already deeply engaged in the process of funding, researching, planning, and designing market-oriented applications for a wide range of fiber optic and photonic technologies. By contrast, many American firms appear to be waiting in the wings, biding their time, hoping for Federal assistance, and unwilling to commit substantial corporate funds for products that might not reach the market for 10 years. If fiber optic and photonic technologies do indeed supplant large portions of the consumer electronics and computer industries—as some analysts argue they will—the implications for the civilian side of the U.S. economy and its ability to supply the military will be enormous. For this reason, the case studies, which are located in a separate volume of appendies to this report, all address the question of the health of domestic industry, specifically analyzing the threat of destructive foreign competition now and in the future.

The purpose of the second question—concerning divergence and convergence in dual-use technology—is to make explicit the differences and similarities between military and civilian technologies and their various applications. As technological divergence between the two sectors increases, it becomes more difficult for the military to draw on the resources of the civilian sector of the economy. Absolute divergence between military and civilian technologies would mean that by far the largest portion of the technology and industrial bases in the United States and around the world would be unavailable to the military. This is clearly not the case. Indeed, a basic strength of the West is that technological innovation is rooted in society and not in the military. Nevertheless, there is a widespread belief among many defense planners and technologists that military and civilian technologies are inherently different, because weapons systems must push the outside envelope of performance, must be built to sustain battlefield environments, and are expected to survive up to several decades of readiness and training missions.

Critics of this position contend that it is possible to plan for convergence of military and civilian technologies, even in early development, by harmonizing otherwise divergent standards and specifications. They believe that much divergence is the result of a military fixation on achieving technical performance levels that may or may not be decisive in warfare or desirable from a training and maintenance perspective. They believe that civilian products can be as rugged as those built to military specification. There are, for example, few environments more hostile than the one under the hood of a car, where semiconductor devices are hard-mounted to the engine block.

Many observers agree that in any dual-use industry there will be strong convergence between the military and civilian technologies themselves, and potentially significant divergence when it comes to end-use. Clearly, there are military applications that will never find expression in civilian life, but at the same time it appears to be possible to substitute commercial off-the-shelf (COTS) products for Milspec items[4] in some of the most advanced weapons systems. But the relationship between civilian and military technologies is far more complex than arguments about the adoption of finished pieces of hardware can suggest. It is evident that civilian technology that could be important to the Armed Forces will be irrelevant if military officials—from general officers to program managers—reject suitable civilian parts in favor of items developed under contract with the government. And it is likely that Service acquisition managers will continue to resist civilian technology and components until the incentive system is changed. At present, many managers avoid new technologies available in the civilian sector, because the acquisition system forces them to assume responsibility when such a part or component fails, thereby jeopardizing their careers. Most prefer to use older technologies, waiting until the specifications, standards, research, and testing are complete—and the risk of failure is eliminated or can be transferred to another program.

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[4] Milspec items are parts or systems formally specified in the body of Military Specifications and Standards published by the Department of Defense.

In the sphere of complex, information-intensive military systems—whether involving weapons or not—the utility of civilian technology and applications must be addressed case by case. For each of the cases in this report, an effort was made to analyze the extent of convergence and divergence of civilian and military technology, and to explore existing and potential areas of overlap. The case studies attempt to sort out the extent to which divergence is technologically necessary and the extent to which it is a product of military culture as well as economic incentives for the contract industries on which the Services depend.

The final question asked earlier, regarding impediments to military use of civilian technology, requires an analysis of the barriers to the fluid exchange of technology between the military and the civilian economies. When OTA began to investigate questions of dual-use technology, complementary complaints surfaced from within DoD and from civilian sector managers. Military technologists asserted that while there were many advanced and desirable technologies in the civil sector, the military encountered difficulties in gaining access to some of them. In addition, senior defense officials indicated that some military contractors had diversified into the civilian sector of the economy with the intention of getting out of the defense business altogether. These officials cited a need to reduce red tape and to make doing business with DoD more stable and predictable. The other side of the complaint—which first emerged from managers of small, entrepreneurial firms—was that doing business with the government involved difficult adjustments, including compliance with outdated military specifications, cumbersome auditing and reporting procedures, and possible compromise of proprietary information. They considered DoD to be a very difficult customer, often too costly to pursue for commercial purposes. The bottom line is that DoD may have to buy advanced technology from companies that do not need, or even particularly want, its business.

Accordingly, it is important to investigate the processes by which specific technologies move between the civilian and military sectors. The existence of significant barriers—whether technical or institutional in character—points to severe deficiencies in national security policy. If security rests to a large extent on the health of the domestic economy and its ability to produce technology and materiel for the national defense, then any substantial inability of the military to draw on civilian technology and industrial resources constitutes a serious and presumably unnecessary liability. If civilian high-technology industries erode significantly in the United States, or if the government loses the ability to exploit the civilian technology base efficiently, it amounts to the same thing. The OTA case studies specifically investigate the extent to which and under what conditions existing barriers are technical in nature, and the extent to which they are due to institutional considerations, including regulatory, legal, and administrative factors.

The focus on the problem of the transition of technology between the civil and military sectors of the economy served as a principal criterion for the selection of the three technology case studies in this report.[5] Fiber optics is a high-technology industry that is well-established in the civilian sector, both domestically and internationally, but which has lagged significantly in the military sector where it has numerous potential applications. On the other hand, advanced polymer matrix composites were developed in the aerospace industry for military purposes. They have only begun to find markets in the civilian sector, even though they could be employed extensively in the construction, civilian aerospace, automotive, and medical instrumentation industries, among others. Finally, software is a case where the technology is advanced and resident in both sectors of the economy, but where each sector still encounters difficulty in drawing on the resources of the other.

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[5] This chapter employs a research strategy based on the method of structured, focused comparison. See Alexander L. George, "Case Studies and Theory Development: The Method of Structured, Focused Comparison," in Paul Gordon Lauren (ed.), *Diplomacy: New Approaches in History, Theory, and Policy* (New York, NY: The Free Press, 1979), pp. 54-59. See also, Alexander L. George, "Case Studies and Theory Development," a paper presented to the Second Annual Symposium on Information Processing in Organizations, Carnegie Mellon University, Oct. 15-16, 1982, pp. 25-34.

[6] The following three sections present summaries of the results of each of the cases as they apply to the three principal questions addressed in this chapter. The reader is referred to Appendices D, E, and F in Volume 2 of this report for more in-depth analysis and documentation.

HEALTH OF THE DUAL-USE INDUSTRIES[6]

Are civilian high-technology industries, those that are critical to the military, eroding in the United States? The story is somewhat different for each of the three high-technology industries considered in this study.

Fiber Optics

Over the past decade, the fiber optics industry has realized tremendous growth, not only in production and sales, but also in the scope of the technology itself. It is a vital technology whose future patterns of development and diffusion have strong economic as well as military implications. Military planners recognize the technical superiority of fiber-based communication systems over those that employ coaxial cable or twisted copper wires. Many analysts believe that fiber optic and related photonic technologies will eventually exert an impact on the world economy comparable to that of the electronics revolution of the 1970s and 1980s.

The worldwide fiber optics industry is characterized by overcapacity and intense competition, with many advanced industrial nations already designating fiber optics as an essential national capability. By 1980, definite patterns had emerged in the way that OECD[7] member governments would respond to the strong growth potential of fiber optics markets. In the United States, large, vertically integrated firms like ITT and AT&T had begun to invest heavily in fiber optic R&D.[8] An early lead in fiber development was established by Corning Glass Works, which holds many of the most important patents in the field. Major cable makers were targeted for takeover by firms seeking to position themselves for future fiber optics business that had not been principally associated with the telecommunications industry.

In contrast to the United States, the Japanese government pursued a deliberate strategy of sponsoring a domestic industry, insulating home markets from foreign competition, building up a highly capable, vertically integrated industry with significant overcapacity, and encouraging export of quality systems to Europe and the United States. NTT, MITI, and KDD[9] (the Japanese international communications agency) initiated a carefully orchestrated campaign. NTT (then an official government agency) led the effort, conducting and promoting fiber optic and optoelectronic research, working principally with three companies, Sumitomo, Furukawa, and Fujikura. At the same time, KDD set up a long-term program to develop all aspects of the technology necessary for submarine fiber optic systems. And MITI sponsored two substantial research projects, the Hi-OVIS program and the Optical Measurement and Control System R&D program. By the mid-1980s, Japanese optoelectronics companies had developed technology on a par with the best in the world, and had established a major position in world markets for fiber optic systems.

European countries generally appeared to take a middle ground, with the national PTTs (state-run public telecommunications monopolies) establishing R&D programs (such as BIGFON in West Germany) and actively seeking to promote the interests of their domestic industries. In Sweden and the Netherlands, the private sector appears to have taken a stronger role. Most European Community (EC) member states have designated fiber optics as a critically important technology, and the national PTTs have tended to favor a few domestic suppliers of equipment and cable. The PTTs provide centralized planning and control of the telephone network and have supported the introduction of new technology into that network by sponsoring trials and demonstration projects. The present configuration of national policies would change dramatically if a pan-European policy develops in the future.

As a result of these differences in policy and approach, U.S. firms face stiff competition at home—while they are effectively barred from substantial penetration of some important foreign markets. Nevertheless, representatives of some American fiber and optoelectronic companies believe that the United States presently maintains a technological lead in virtually every area of fiber optics, but that this lead is eroding. The American position was established and is still based on intense competition for sales to American telephone companies. Some analysts believe that because the industry is robust, officials in Washington should stay on the sidelines and allow market forces to continue to strengthen an emerging industry in which the United States has already proven itself to be particularly sturdy and capable.

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[6] The following three sections present summaries of the results of each of the cases as they apply to the three principal questions addressed in this chapter. The reader is referred to Appendices D, E, and F in Volume 2 of this report for more in-depth analysis and documentation.

[7] OECD: Organization for Economic Cooperation and Development.

[8] International Telephone and Telegraph, and American Telephone and Telegraph.

[9] Nippon Telephone and Telegraph, Ministry of International Trade and Industry, and Kokusai Denshin Denwa.

Many analysts are less optimistic about the competitive status of the fiber optics and optoelectronics industries in the United States. They believe that the success of the U.S. industry is by no means assured, but instead will hinge on a variety of critical factors. The most important of these are discussed briefly.

First, the future health of the U.S. fiber optics industry largely depends on the extent to which it can sell fiber and optoelectronic devices to the telecommunications companies. That business, in turn, depends on building fiber optic links to individual homes across the United States. Legislators and regulators have tended to shift responsibility for the national telecommunications infrastructure to market forces and to the courts. Some analysts believe that the present regulatory structure—one that effectively separates telephone from television delivery systems and inhibits the spread of telematic (online) services—retards the development of the optoelectronics industry in the United States. At the same time, huge, vertically integrated Japanese and European firms are gaining experience in the production and commercialization of large-scale fiber optic local area networks (LANs) in their home markets.

A second area of concern focuses on the lack of international standards for fiber optic systems and associated optoelectronic devices. While international standards are developing, especially for integrated services digital networks (ISDN), progress in this area is slow for an industry that is innovating quickly. Different countries have tended to adopt different standards, and standards have sometimes been used as non-tariff barriers to protect home markets for developing industries. Some industry representatives believe that Japan and the European nations have advanced farther towards setting standards than has the United States, and that they may succeed in imposing de facto standards on the competition in the future.

Third, penetrating foreign markets—especially in Japan but also in some European countries—is still difficult for American firms. This disadvantage for U.S. companies is compounded because future expanded demand for fiber optic systems is expected to occur first in foreign markets, where domestic manufacturers are favored.

Fourth, most European producer nations and the Japanese Government have designated fiber optics as an essential technology of the future and they subsidize R&D in the optoelectronics field. In the United States, government assistance has been confined largely to the military, and U.S. companies have tended to pursue research and development on an ad hoc, isolated basis.

Finally, the United States continues to maintain a regime of export controls for fiber optics that is more restrictive than that of its CoCom partners and non-CoCom nations such as Sweden and Finland. U.S. unilateral controls have tended to exclude U.S. firms from participating in some markets that are open to the European and Japanese competition. In addition, some foreign firms are reluctant to buy U.S.-made optoelectronic parts and components, because they fear that U.S. Government prohibitions against exporting goods to third-party countries will apply to them.

Software

Although the U.S. software industry currently dominates world markets, both technically and economically, its continued superiority will depend on a number of complex factors. The industry faces difficulties in meeting growing demand for all types of software—packaged, integrated systems, and custom-built. International competition is increasing as other nations—particularly Japan, France, the U.K., Korea, and India—establish software production capacity and seek to penetrate global software markets. U.S. software firms increasingly face tariffs and foreign trade policies that restrict imports of U.S.-developed software. Enforcement of intellectual property rights in international software trade is lax. And finally, as the world market continues to grow, its composition will undoubtedly change, and the demand for new types of software may create advantages for companies in foreign nations. These factors are addressed below.

The ability to meet the growing demand for software, and the ability of the United States to maintain its dominance of the software market, depends on the supply of computer programmers and the technology available to them. U.S. companies cannot meet the demand for software with the present number of computer programmers. The shortfall of software professionals in the United States is estimated at 50,000 to 100,000 and is forecast to grow steadily over the next decade. The lack of qualified software developers may be part of a larger shortfall in trained science and engineering professionals in the United States. Beyond any doubt, there is a serious shortage of rigorous software engineering programs at U.S. colleges and universities.

Many programming methods and practices used in U.S. industry today are primitive when compared to sophisticated software engineering techniques. The software development process can be improved through the use of formalized and automated engineering techniques. These support the iterative building and testing of software prototype systems, allow for the reuse of software components, and accommodate the complexity of software systems. Widespread use of these technologies in the United States is impeded by the existence of a large, embedded, heterogeneous software base.

The growing cost of software maintenance is directly related to the failure to recognize software engineering as a scientific discipline and to the lack of trained software engineers. Software maintenance—the modification of software to correct errors and to incorporate changes or enhancements—has become the primary cost in most software systems. Present estimates indicate that in fiscal year 1990, DoD will spend 80 percent of its $20 billion software budget on maintenance.

Approximately 40 percent of the packaged software[10] revenues earned by U.S. firms come from outside the United States. This share is threatened by the software industries in Japan, France, the U.K., Korea, India, Taiwan, and Singapore. Japan is the strongest competitor primarily because of its advanced hardware industry and the propensity to take advantage of standardized technologies and develop marketable products from them. A principal strength of the Japanese is the ability to close large portions of their domestic market to foreign products, and simultaneously to penetrate U.S. markets with systems software developed using U.S. standardized designs.

A comparison of the U.S. and Japanese industries shows that, while the level of software technology in both countries is similar, Japanese firms create more disciplined software engineering environments in which the use and production of tools is more widespread. As a result, Japanese programmers are much more productive than their U.S. counterparts. In contrast to the U.S. industry, Japanese software companies tend to invest more money in basic technology and to distribute this capitalization across the entire firm, rather than limiting it to particular software projects. Many Japanese companies view programming as an applied science. Their "software factories," which reuse approximately 30 percent of previously developed software, have an error rate one-tenth that of U.S. companies, and have the potential to produce lower cost and higher quality software.

As U.S. software companies operate in world markets, they are increasingly subjected to intellectual property violations and infringements. U.S. domestic intellectual property protections (copyrights, trademarks, trade secrets, and proprietary data) are insufficient to protect U.S. interests in many foreign nations, where the penalties for intellectual property infringement can be less than the resulting profits. This problem is most pronounced in less developed countries, which have little to lose and much to gain by not honoring U.S.

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[10] Packaged software is software that is commercially developed and broadly marketed, as opposed to custom software, which is developed to meet the particular needs of a specific user.

regulations. Japan is also cited frequently for violations.

Additional economic loss for U.S. industry is attributed to the restrictive trade policies of many foreign nations, which serve to foster native software industries at the expense of U.S. firms. Import quotas, discriminatory taxes, local ownership requirements, embargoes, and preferential treatment for locally produced goods are among the common policies that discourage or preclude U.S. firms from seeking business. These practices are most pronounced in Brazil, India, Mexico, and Korea.

Polymer Matrix Composites

Although the U.S. DoD drives the development of composite materials technology (historically through its R&D funding and now through its aircraft/aerospace purchases), advanced composites is a global business conducted by companies (U.S. and foreign) with broad international interests.[11] Large chemical and petroleum companies are suppliers of fibers and composite parts around the globe.

The world PMC industry is extremely intertwined in terms of corporate vertical integration, integration with its major end-use market (the military aerospace prime contractors), and with multinational chemical and petroleum interests. Advanced composites are formed in a series of stages, each of which corresponds roughly to a different industry—raw materials, fiber preparation and shaping, and components for end-use.[12] In recent years, raw material suppliers such as Amoco, British Petroleum, Phillips, Shell, BASF, Ciba-Geigy, Du Pont, and Hercules have moved downstream into fibers and shapes, where there is more value added in the products. Most of these companies buy from, sell to, and compete with each other for business from military prime contractors. At the same time, defense aerospace companies, which had relied on specialized companies for part forming services, have moved upstream, making parts in-house and buying only the raw materials.

In this discussion, two distinct stages of corporate integration can be defined: material suppliers and end users (including intermediate material suppliers). Fibers are sold as standardized commodity materials. End users (and intermediate suppliers) develop individually tailored structures for each application. Because of this dichotomy, fiber suppliers conduct a different style of business, with different issues and concerns, from that of the end users.

Material Suppliers

Carbon fiber is a principal ingredient in the production of advanced PMCs. About 65 percent of the U.S. carbon fiber market is in the aerospace industry. Over half of the U.S. aerospace market for fiber is military. Defense applications are projected to grow by as much as 22 percent annually in the next few years. The U.S. military market is a primary target for foreign companies producing carbon fiber composites, because it is the largest, most advanced, and most attractive in terms of sales and profitability. The second largest market is in the Far East, where carbon fiber products are used to make sporting goods.

Worldwide, carbon fiber capacity is twice the current market volume. Japan and the United States have about equal capacity. Japanese companies manufacture a carbon fiber precursor, which is then sold to U.S.-based carbon fiber suppliers (mainly Hercules), which is in turn the major supplier of fiber for military programs. At present, no Japanese carbon fiber is supplied directly to U.S. military programs.

U.S.-based industry is continuing to add carbon fiber capacity—about 1 million pounds in 1988. Accordingly, there is and will continue to be a great deal of excess capacity both in the United States and in world markets. While the United States has a large fiber overcapacity compared to domestic market requirements, most of the world excess capacity is concentrated in Japan.

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[11] The discussion of PMCs draws on a previous OTA assessment. See U.S. Congress, Office of Technology Assessment, *Advanced Materials by Design: New Structural Materials Technologies*, OTA-E-351 (Washington, DC: U.S. Government Printing Office, June 1988).

[12] In the manufacture of PMCs, highly processed carbon fibers are chemically treated and bonded with a matrix material. The material is shaped during this process which involves heating and compressing it into a mold. These shapes are then finished by machining, and become final products such as airplane wings and tennis rackets.

Although Japan is the largest manufacturer of carbon fiber in the world, it has been only a minor participant to date in the advanced composites business. Japanese companies have been limited by licensing agreements from participating directly in the U.S. market. In addition, Japan does not have a domestic aircraft industry to which advanced PMCs could be sold, although it is trying to establish one through a joint venture with Boeing and through its decision to build the FSX fighter. Japanese companies are building a strong position worldwide in PMC technologies.

End Users

The United States leads the world in developing and using advanced PMC technology, based largely on the strength of its military aircraft and aerospace programs. Nevertheless, foreign commercial end users outside the aerospace industry are more active in experimenting with these new materials than are their U.S. counterparts. Western Europe leads the world in composite medical devices, partly because the regulatory environment controlling the use of new materials in the human body is less restrictive in Europe than in the United States. The EC is taking additional steps to commercialize advanced PMCs. For example, the EUREKA Carmat 2000 program proposes to spend $60 million through 1990 to develop advanced PMC automobile structures.

The U.S. market on the whole is projected to grow faster than the world market, based on the assumption that the military demand for PMCs will expand rapidly over the next 5 years. Although the number of U.S. military aircraft being built is declining, composites are replacing much of the metal on airplanes. For example, the F-16 has 260 pounds of advanced composites per aircraft, while the V-22, which recently moved into production, will have from 8,000 to 9,000 pounds per aircraft. However, growth is expected to level off in the middle 1990s as advanced PMCs move into all of the structures for which they are suited.

Foreign production of U.S. aircraft components is increasing, and manufacturing of composites for commercial aircraft is moving offshore in many cases. A significant number of foreign companies fabricate parts for U.S. aircraft manufacturers. This is largely the result of economic offsets that are used to secure sales of aircraft by offering portions of the aircraft fabrication to companies from the buying nation. Such sales enhance technology development in, and the potential economic competitiveness of, foreign-owned advanced composites businesses, possibly at the future expense of U.S.-owned firms.

In the past few years, participation of Western European-owned companies in the U.S. advanced PMC market has increased dramatically. This has largely taken the form of acquisitions of U.S.-owned companies. Industry analysts indicate that U.S. carbon fiber facilities have been sold, due to corporate "impatience" resulting from the need to report favorable quarterly earnings. In general, foreign corporations tend to be more patient. Despite excess worldwide capacity and profitability problems, the Japanese have not sold any carbon fiber facilities. As a result of extensive acquisition of U.S. firms, foreign makers of advanced materials have entered the U.S. aerospace market and share the technology leadership that participants enjoy.

CONVERGENCE OF MILITARY AND CIVILIAN TECHNOLOGIES

Do military technologies and their applications diverge significantly from their counterparts in the civilian sector of the economy?

Fiber Optics

The distinction between tactical and fixed-plant fiber optic systems is important. Tactical systems require rapid mobility. Although fixed-plant systems are installed directly in the ground or in conduits, most tactical systems must be placed on the ground, strung above the ground, or deployed at sea. While there are no significant limitations on cable length for fixed systems, tactical systems must be configured so that they can be set up and retrieved quickly. In addition, cable used in tactical communications must be more flexible and durable than that used in fixed-plant systems. While optical splicing may be used for many fixed applications, connectors are necessary due to the requirement for mobility in a tactical environment. And finally, batteries or other local sources of power are usually required to drive sources and repeaters in tactical systems. Generally speaking, shipboard fiber optic systems can be considered as fixed plant.

Do such differences between military and civilian applications translate into differences in the technology itself or in the way that R&D for fiber optics must be conducted? The answer is a qualified "No." For fixed-plant systems, military requirements would differ only marginally, if at all, from those used in private-sector businesses or for local area subscriber networks. For a large percentage of military applications—wiring the Pentagon, the DoD laboratories and R&D facilities, and the military bases—the technology is broadly available from the civilian sector. In addition, fiber optic systems deployed on ships would be similar to LANs now undergoing trials in the private sector in Japan and in the United States.

Optical sensors have enormous potential in a wide range of applications both military and civilian. Many of the major sensors used by the military—or under development—are analogous to those used in the civilian sector. One fiber optics group in the Navy has tested 54 different sensors developed for civilian purposes and found that most of them do not perform adequately in a military context. They concluded, however, that the civilian sensors should not be discarded and replaced by sensors built to military specification. Such specifications do not yet exist, and the process of writing them and getting them approved would take years. Instead, the group takes the approach of addressing the military requirement by modifying commercial products so that they are suitable for the particular military task for which they are envisioned.

Their objective is to use the existing technology—which they believe is far more advanced than that which the Services presently need. For example, industry already has endoscopic devices for looking into machinery and into places where electronics cannot be placed. This is not a new or radical technology. These devices represent basic technology with new applications. In this approach, DoD's challenge is to figure out how to take the technology that is available—not a radical departure from it—and use it in a military setting.

Despite the decidedly military character of the FOG-M missile,[13] its designers indicate that the Army has been able, for the most part, to use optical fiber that can be produced on modified commercial manufacturing equipment. The fiber companies have entered into earnest discussion with the FOG-M program, because they anticipate a run of fiber that might reach a volume of up to 2 million kilometers. There are special military requirements in the way that the fiber is wound on the spool, in the fiber design, and in the materials that are used to attach the fiber to the spool. But these do not translate into large differences from civilian technology, nor do they require significant changes in the way that R&D is carried out. The military requirements can be met if civilian fiber companies are willing to develop the modifications.

Software

The software industry is increasingly divided into two camps, one that is dedicated to military interests and another that supplies the commercial world. These two sectors have been present since the birth of the industry, and exchange between the two was assumed to be the norm, not the exception. But there are significant indications that divergence between these groups is increasing, which may contribute to a weakening of the U.S. software technology base.

The underlying software technologies are very similar in both the military and civilian sectors, and divergence becomes noticeable only in the detailed requirements for specialized applications. Convergence between civilian and military software industries is most noticeable in the small-scale applications and systems software areas. Both sectors use packaged COTS software for the majority of their small-scale software applications, such as personal computer (PC) based programs and office automation products.

Similarities in the applications of software are not limited to PC-based and systems software. Analogous applications of large-scale software systems also can be found in both sectors, including software developed for avionics, telecommunications, and embedded systems. But while the applications are similar, military and civilian environments place different, sometimes opposing requirements on the software that controls these systems. This is particularly true for large-scale, mission-critical applications in the DoD.

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[13] The Fiber Optic Guided Missile (FOG-M), now in full-scale engineering development, pays out optical fiber from a bobbin, enabling the battlefield operator to target the missile with a real-time video image emanating from a camera in the nose of the missile.

Thus, different requirements, as well as differences in scale, create two distinct software industries in the large-scale applications area. The industry divergence is illustrated in avionics systems software, where military requirements for high-performance avionics are exchanged for high survivability and safety in civilian avionics. The significance attached to software requirements by each sector, and whether they become rigid specifications or economic trade-offs, partially explains why there is little transfer of software between the military and civilian sectors in the embedded and large-scale applications.

Military requirements for custom-built and embedded software are generally far more rigid than civilian requirements. Once documented and approved in the design stage, specified requirements govern the subsequent development of the software.

The need for specific performance and operational characteristics is evident in many DoD mission-critical systems. It is necessary to require nearly 100 percent reliability for a missile guidance system or multi-level security in a networked defense communications system. But when these requirements are transferred unnecessarily to other military systems, the cost of development increases and the ability to use analogous civilian applications or commercially developed software diminishes.

Many of the requirements often identified as unique to military applications—for example, multilevel security, data encryption, interoperability, survivability, and high reliability—are equally appropriate in banking, insurance, commercial flight control, and other civilian applications. Indeed, many features incorporated into military systems could be transferred to civilian applications and vice versa. But while these features are desirable and appropriate in civilian applications, their implementation would be based on economic and risk analysis. In the civilian sector, if the cost of implementing a requirement exceeds the expected return, then the requirement is usually deleted or deferred. This analysis and design-to-cost approach rarely occurs in military software acquisitions, although similar accommodations will be more likely if military software costs continue to escalate.

A more recent divergence between the military and civilian sectors of the software industry relates to the military's mandated use of a single high-order language, Ada, in its mission-critical software systems. DoD's sponsorship of Ada began in 1974 when the "software crisis" was first recognized and acknowledged to have potentially serious consequences for the military's ability to maintain and operate its many computer systems. In 1983, Ada was approved as a standard by the American National Standards Institute (ANSI) and by DoD as Military Standard (MIL-STD) 1815A. By 1987, Ada was approved as an International Standards Organization (ISO) standard.

The DoD Directive that Ada shall be the single high-order language used in command and control, intelligence, and weapons systems has no counterpart in the commercial environment. With the exception of civilian avionics systems, Ada is not widely used in U.S. commercial applications. Instead, civilian-based software continues to be implemented in the language considered to be best for that particular application—whether it be COBOL, a fourth generation language, or any other computer language. As new DoD computer systems are developed, the convergence of new software technologies and the ability to transfer software between the two sectors will depend a great deal on several factors: first, the civilian sector's acceptance of, and demonstrated use of, Ada; second, DoD's willingness to grant waivers to its Ada mandate; and finally, the military's acceptance of, or ability to, incorporate commercially developed, non-Ada software into its computer systems.

Polymer Matrix Composites

There is both convergence and divergence in military and civilian applications of advanced PMC technology. In general, military and civilian markets have different technical and cost criteria for the selection of materials and process technologies. Convergence and divergence occur simultaneously in different aspects of the PMC industry and its markets.

Various segments of civilian and military markets place different emphasis on performance and cost. In the commercial aerospace, military non-aerospace, automotive, and construction markets, for instance, acquisition costs and operating expenses are the major purchase criteria, with a progressively lower premium placed on high material performance. In military aerospace, biomedical, and space markets, on the other hand, functional capabilities and performance characteristics are the primary purchase criteria.

Although general functional requirements (e.g., low weight, high strength for primary structures, lower strength for secondary and nonstructural parts) lead to convergence between the military and commercial aircraft sectors, the stringent mission requirements for military aircraft drive the use of advanced composites in the military. For space applications and fighter aircraft, advanced PMCs are more than just one of many competing materials. They can be the enabling technology for mission requirements because of their high strength-to-weight ratio.

The use of lower cost materials (such as glass-reinforced composites, or fiberglass) in general means more weight and lower performance in the traditional aerospace sense. Industry representatives assert that battlefield conditions require that weapons systems weigh less. That was the initial reason for the attractiveness of composites, particularly graphite-reinforced composites. While lower costs are desirable in the military aerospace sector, performance remains the main driver.

According to advanced PMC industry representatives, cost currently limits market growth and the transfer of high-performance military PMC technology to the commercial sector. Carbon fiber is priced at about $15 to $20 per pound. Chemically treated fiber, called prepreg, sells for $35 to $40 per pound; and the cost of finished aircraft structural components is between $250 and $600 per pound. Aluminum structures cost about $85 a pound, including 2 hours of labor and $5 of material. Some 70 to 80 percent of the cost of a finished advanced PMC part is due to fabrication costs.

Many developments have wide applicability across both the civilian and the military arenas. There is synergism between military and commercial aircraft production in resins and fibers, the way materials are stitched together, and the way they are used. For military and commercial aircraft, the structures made from composites (e.g., wings, tail, and empennage) are similarly complex to fabricate. The basic method of production of aircraft parts is also similar: coating of continuous fibers with resin, careful placement of fibers, and application of heat and pressure to form the structure.

However, military requirements may make it necessary to modify the fabrication process. For example, pultrusion is typically used in the commercial market to form beams. Military applications need superior load-carrying capacity, so that for military applications the pultrusion process must be modified to impart different properties to the fabricated part.

From a broad perspective, the military community often requires custom-made hardware, while commercial industries look for off-the-shelf products combining low cost and high quality. Many military and space hardware applications are very specialized and require low production volumes. The automotive industry, on the other hand, is driven by low costs and high production rates. Between the aerospace and automotive advanced PMC markets, a variety of other market applications (including the non-aerospace military market) have production rates higher than military aerospace, cost objectives similar to automotive applications, and moderate performance requirements.

Military and commercial aircraft both experience similar environmental conditions, and thus require similar lightning protection, corrosion resistance, fatigue resistance, and material toughness. While the technical requirements for PMCs in commercial aircraft are comparable to those for fighter aircraft, there are some major differences related to peak G-loading and maneuverability, repair strategies, stealth, radiation hardening, and design temperatures.

Military and commercial aircraft have inherently different duty cycles. Military aircraft are on the ground a significant portion of the time, while commercial airplanes are in the air much of the time. Commercial aircraft designers are concerned with structural fatigue, and with takeoff and landing duty cycles. The dominant factors for maintenance of military airframes are ground temperature, corrosion, and exposure.

BARRIERS BETWEEN THE CIVILIAN AND MILITARY SECTORS

What are the principal barriers, both technical and institutional, that inhibit military access to civilian technology and vice versa?

Fiber Optics

In order to do any substantial amount of business with the DoD, fiber optics companies have found it necessary to create a separate corporate division. To meet government regulations and specifications, fiber optics businesses must organize many of their principal functions differently—including accounting, personnel, auditing, R&D, production, advertising, marketing, and management information systems. They must also adjust their business psychology and profit orientation. Successful fiber optics and optoelectronics companies invest heavily in research, develop a superior product, realize large profits, and plow their earnings back into the R&D effort. This business environment contrasts sharply with one of government-subsidized research and regulated profit margins.

The question of how to specify fiber optic systems and devices for the military poses what amounts to a paradox, both for the industry and for the government. The problem is that optoelectronic and fiber optic technologies are changing so rapidly that no one can agree on standards. DoD is confronted with the problem that, by picking a standard, it may lock itself into an obsolete technology or an application that no one in the civilian sector is willing to build at a reasonable cost. This is because the military wants to nail down prescriptive standards[14] in a field that is changing from month to month. The alternative is to adopt performance standards essentially specifying, in a general way, the characteristics that a part or component must meet, and then leaving it to industry to figure out the specifics. This would, however, make it more difficult to conduct competitive procurements. The range of competing designs might be very wide, and it would be necessary to trade off price against quality.

Industry executives suggest that the military generally does not recognize the capabilities of the commercial sector. From the industrial perspective, this is due to "the momentum factor" and "cultural conservatism" in the military, two substantial barriers to the large-scale introduction of fiber optic technology. The former proposes that the Services have committed themselves to older communications and sensing technologies, many of which are not compatible with fiber optic systems. According to the latter, there is little incentive for program managers to seek out a new technology and put it into a weapon system, particularly if the technology is changing rapidly and proposed parts or components are not fully specified.

The lack of industry standards exacerbates this already difficult internal problem. From the DoD perspective, there is no way that acquisition managers can make mass-scale purchases from civilian industry—and this is where the technology resides—in the absence of performance, design, and testing specifications. These are considered essential to the acquisition process.

By insisting on the use of existing specifications, the military can create barriers to the introduction of a new technology—for example, when a large civil-sector company attempts to install a standard fiber optic telecommunications system for a military base. DoD could procure regular commercial products, since there are no special military requirements. But it is very difficult to install such a system on a base. If there are no existing military specifications and standards, DoD is reluctant to buy a system. If there are military specifications, they are unlikely to correspond to existing commercial products, because civilian technology probably advanced while the military specifications were being written and approved. In this case, the Defense Department will end up paying more for a less capable system than would a commercial purchaser. Somehow, DoD must learn to make decisions about what it wants—either by writing specifications, modifying specifications, or carrying out procurements without specifications—in a matter of a few months.

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[14] In general, "prescriptive standards" specify how something is to be made or what it is to be made from. In contrast, "performance standards" specify only the resulting capability or performance level to be achieved.

Industry executives and analysts point to several key reasons why some optoelectronics and fiber optics firms have difficulty in selling their products to DoD, and others are reluctant to do business at all. Those most often cited include: 1) DoD cannot guarantee firms that funding will be available for authorized projects; 2) DoD seeks to acquire data rights that would compromise large R&D investments; and 3) to do business with DoD, a firm must fundamentally alter its corporate structure, policies, and overall intentions. Each of these problems is discussed below.

In a somewhat ironic case, a fiber optics company licensed its technology from a university research program funded by DoD, and is now unwilling to do business with the government. It is a small, highly profitable company that is limited in the extent of money and technology that it can leverage for any given purpose. Its executives are very reluctant to take contracts with DoD, because they cannot afford to hire specialists who can respond to DoD regulations, contracting procedures, auditing practices, and other requirements. They are unable to support the cost of research and gearing up for production, unless there is a definite market for the product in question and the opportunity to realize substantial profits.

In the civil sector, a company can develop long-term relationships with its suppliers and customers. Government notions of fairness and competition rules make it difficult to sustain such relationships, as does the turnover of contracting personnel.

A second major problem, cited by some industry analysts, is that government procurement officers and regulations do not recognize the extent to which fiber optic and optoelectronic technologies are driven by R&D activity. Government agents tend to demand as many data rights as they can get in any given contract. Most fiber optics firms are unwilling to share their data, because they believe that such data can be used to reveal a core of proprietary process information.

For optoelectronics and fiber optics companies, the problem of protecting proprietary rights comes at the very beginning of a decision to take a government contract. If the company has not worked with DoD in the past or if the military segment of the business is small, many executives tend to skirt the problem by avoiding government contracts.

A third major impediment between DoD and civil-sector fiber optics firms is the perception on the part of industry executives that they are simply ill-equipped to do business with DoD. This is in part a consequence of the divergence of business practices in the military and civilian sectors of the economy, and partly a result of inflexibility on the part of government. To do substantial business with DoD, managers would have to learn to live with and respond to regulatory, reporting, accounting, and auditing requirements that are largely incompatible with their own systems, and that do not make sense in the context of civil-sector business.

Software

Despite similarities in the technologies available to the civilian and military software sectors, differences in their respective acquisition strategies obstruct the exchange of software technologies and applications. Persistent barriers to the transfer of technology, methodologies, and products between military and civilian interests are identified below.

In 1987, a DSB task force reported that both technical and management problems are evident in military software development, with the latter being more significant.[15] These management problems relate to the manner in which DoD procures software, and they represent major barriers to the exchange of software technology between the civilian sector and DoD.

According to industry representatives, the principal problem is the bureaucracy and administrative overhead associated with DoD acquisition procedures. The requirements regarding procurement, design, development, and maintenance of DoD software are set forth in DoD-STD 2167A. As a government review mechanism, DoD-STD 2167A references and directly or indirectly requires compliance with many additional standards, directives, data item descriptions, and Federal Acquisition

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[15] Defense Science Board, "Report of the DSB 1987 Summer Study on Technology Base Management," prepared for the Office of the Under Secretary of Defense for Acquisition, December 1987.

Regulations (FAR). As is true of fiber optics companies, in an attempt to comply with contractual obligations, commercial software vendors must employ specialists who are fluent in military regulations, government reviews, documentation, and accounting procedures. These requirements and associated legal issues have forced many DoD contractors to establish autonomous divisions for conducting business with the government. As a result, few civilian software firms regularly contract with DoD.

Defense Department acquisition procedures and contracting practices limit the number of potential vendors and discourage established contractors who already work for the military. Civilian firms that contract with DoD receive no guarantee of a continued relationship with the government, achieve poor profit margins, and often lose the rights-in-data to their software.

Although software firms guard proprietary information closely, this property is often transferred—by contract—to the government. Despite the flexibility allowed government contracting officers to negotiate less-than-exclusive rights to data in software acquisitions, commercial venders generally lose most, if not all, of their intellectual property rights to the software they develop. The government's claim to unlimited data rights is based on the notion that these rights protect the government and ensure public dissemination of publicly sponsored research efforts. In negotiating for unlimited rights to data for its software, the government achieves the ability to maintain and modify its software systems in the future. This practice is intended to ensure fair competition for future software maintenance and reprocurement contracts. Some analysts assert, however, that such policies weaken DoD's ability to negotiate for the best software at competitive prices, because they drive away potential bidders.

Ada has been cited by some civilian software firms as a barrier to doing business with DoD. The directive stating that Ada shall be the "single, common, computer programming language" used in command and control, intelligence, and weapons systems may help in the long run to alleviate the military's software crisis. But because of its relative immaturity, the number of software firms proficient in Ada is limited. The mandate to use Ada appears to reduce the already limited number of firms willing **and** able to contract with DoD.

Some experts cite Ada as an example of the government's tendency to standardize too much, too early. Although the requirement to use Ada for mission-critical applications was arguably premature in 1983, developments associated with Ada have advanced significantly since that time. But many commercial vendors, with the exception of those in the avionics industry, still take a wait-and-see attitude about Ada.

The merits of a single, standardized language, such as Ada, will continue to be debated. Ada's benefits include its embodiment of engineering techniques essential to the development of maintainable software, its support for modular (and reusable) components necessary in the development of large-scale, integrated systems, and its portability among diverse computer architectures. Additionally, because it was standardized early and trademarked, there are no incompatible dialects of the language; such dialects tend to decrease the reliability and complicate the maintenance of software systems. These characteristics have the potential to bridge some of the technological differences between the civilian and military sectors.

Whether Ada becomes an area of convergence, rather than a barrier, remains to be seen. Because DoD is the single largest consumer of software and is committed to the use of Ada, the language will be an important factor in future software technologies. Its potential, though, conflicts with the current situation in which many military mission-critical applications are required to be implemented in Ada, while similar civilian applications will continue to be developed in the language deemed best for each particular project.

Polymer Matrix Composites

Advanced composites technology was first applied in the military sector. Although the PMC industry envisions a very large commercial market for advanced composites in the future, it sees limited commercial opportunities today. PMC suppliers feel that commercial development is the key to profitability in advanced composites, and that sustaining a presence in the military marketplace is a way to pursue it.

As in the other industries under review, military contracting and accounting procedures, and the potential loss of proprietary rights and patentability, may be the costs of participation in the military composites market. Loss of data rights is considered by some commercial sector companies as a threat to their survival in a competitive marketplace. Forfeiting proprietary rights goes against the "corporate culture" in many non-defense companies and fear of such losses inhibits the flow of technology between the defense and commercial sectors. Indeed, technology developed in the commercial half of a company may not be shared with the military half due to proprietary concerns.

These barriers represent inhibitions, but not prohibitions, to the transfer of technology between the civilian and military sectors. Participation by commercially oriented companies in recent defense programs, such as the Low Cost Composite Weapon Program and C-17 subcontracts, indicates that such companies are willing to engage in military programs.

Government business rules and regulations have inhibited the transfer of PMC technologies from the commercial sector into military applications. For example, in 1978 ACF Industries successfully developed an inexpensive glass-fiber composite railroad car based on aerospace technology. DoD repeatedly approached ACF to use this technology in an ongoing defense program. ACF management declined to work with the government, because putting up with government audit procedures was more trouble for the company than it was worth.

Similarly, the teaming arrangement for the Low Cost Composite Weapon Program was designed to augment a military aircraft manufacturer's capabilities with the lower-cost commercial technology of nonmilitary subcontractors. The lack of simple purchase orders for commercial sector contractors and the government accounting compliance requirements met with stiff resistance. The commercial sector subcontractors expressed reluctance to participate on this project, because of the required forms, audits, and the justification of overheads.

In addition, personnel working on highly classified programs sometimes cannot obtain clearance to share nonsensitive information such as generic materials and process technology data. This information is often embedded in classified reports. It is costly for the military or the contractor to employ personnel to extract generic types of information from classified reports.

The DoD has similar problems internally. Some analysts are concerned that there may be technology under development in the "black world" that the rest of DoD could build on but does not know about. PMC industry representatives have indicated that more attention should be placed on the transfer of "black" technology into the "white" technology base.

Industry representatives indicate that the pressure to share data in military markets to reduce costs conflicts with their competitive instincts. Some companies feel that information disclosed to the government would become public and might be used by their competitors in a different market. Nevertheless, some sharing of materials databases is necessary to reduce the currently excessive costs of R&D and processing.

Aircraft manufacturers, parts fabricators, and material companies that contract directly with DoD (or that take subcontracts) often set up separate divisions to comply with government regulations and procedures. Although personnel can be transferred from the commercial divisions or hired from other defense contractors, industry analysts state that everybody in the defense division eventually thinks "government contracting." The overhead charged by that division is typically a great deal higher than that charged by the rest of the company.

SUMMARY OF CASE STUDIES

The case studies send mixed signals about the overall health of the three industries. Each exhibits different strengths and vulnerabilities. The U.S. optical fiber industry is strong today, but it is concentrated in two large companies. These companies face daunting competition in the future, both from the EC and from Japan. In software, U.S. companies clearly lead the world in both sales and technology leadership. But the competition—especially from Japan—is closing the gap, and the United States is experiencing a growing shortage of software engineers. The U.S. PMC industry is strong and thoroughly internationalized. It is also extremely dependent on the Defense Department. DoD has supported PMC technology because it is both pervasive and enabling for a large number of military systems. But the cost to DoD is very great. To date, there is little indication that U.S.-based producers are willing or able to diversify into civilian markets, so long as a lucrative military market exists.

For each of the three technologies, a high degree of technological convergence between civilian and military applications is evident. There are also some applications that are unique to the military for each of the technologies. There is, however, significant divergence between the military and civilian economic sectors for each industry, and this occurs for reasons that are not directly related to the technology itself. In the fiber optics industry, the civilian sector is far in advance of the military in most areas. The software industry is increasingly divided into two camps—one that serves the military and one that does not. Such divergence is rooted largely in differences in the way that military and civilian business is conducted. Of the three technologies, advanced materials shows the greatest divergence between military and civilian applications. There are significant differences in the molecular structure of each end-product because each PMC material must be individually designed. However, automation of the production process and dissemination of data bases would certainly reduce costs and aid in diffusing PMC technology into a variety of civilian applications.

In each of the cases reviewed, the barriers that exist between the military and civilian sectors of the economy are due largely to differences in organization, administration, and business practices, rather than to differences in the technologies themselves. Indeed, this is a principal finding of this study. The reality—that the military often buys less than state-of-the-art technology—is disturbing, both from a national security perspective and in terms of the kind of efficiency that is associated with good government. As we have seen, many companies that produce fiber optic and optoelectronic technologies are reluctant to do business with the government. Barriers to the participation of civilian sector companies appear to be largely generic across many industries. In the case of software, DoD simply does not have access to the best and most advanced civilian talent and products, and there is very little synergy between the military and civilian components of this critical high-technology industry. Advanced composites offer a different view of the same sorts of problems. Because the industry was developed largely by military aerospace companies and other DoD contractors, it makes sense to look for a "spin-off" effect. However, U.S.-based firms that do significant business in advanced composites with the DoD have generally not been successful in marketing their products in a nondefense context.

FINDINGS

The general findings of the case studies are presented below. While they are based on the three cases, they have wider implications for the defense technology base and for other high-technology industries. Detailed findings that are more specific to the individual technologies are presented in the particular case studies, located in Volume 2 of this report.

Overall Findings

1. Two relatively separate economic sectors have evolved in the post-World War II period, one military and the other commercial. Business practices in the two diverge significantly, and substantial barriers impede the transfer of advanced technology between one sector and the other.

2. Nevertheless, the ability of the military to achieve and maintain leading-edge technology in the future will depend in many cases on the health of the corresponding industry in the commercial sector of the economy. Machine tools and semiconductors are well-documented examples.

3. The barriers that stand between the military and the commercial high-technology sectors are largely due to legal, institutional, and administrative factors, and are not inherent in the technologies themselves.

4. The United States is failing to develop and/or maintain a competitive commercial base for some technologies that are important or even essential to military procurement. It is likely that DoD either will have to turn increasingly to foreign suppliers to achieve or maintain state-of-the-art capacities in such areas, or will pay a high price to maintain in-house capacities.

5. Longstanding industrial and trade policies may have to be reformed if the United States is to achieve and/or maintain world-class industrial capacity in support of certain essential dual-use technologies.

Findings Relevant to the Department of Defense

1. DoD faces two central problems in the area of dual-use technology. First, government procurement practices make it increasingly difficult for DoD to obtain state-of-the-art technology in areas where the private civilian sector is leading. Second, certain essential high-technology industries are weak in the United States, and others may not be located here in the future.

2. Due to the magnitude of the investment that is required to create advanced technological capability in a number of critical areas, DoD cannot afford to finance advanced technology and product development across the full spectrum of technologies that are important to the military. Instead, it must rely on innovation and R&D in the civilian sector to pull some technologies forward.

3. Initiatives to increase DoD's access to and use of commercial technology have tended to fail in the past, largely because they did not address institutional and structural factors.

4. Many firms are reluctant to do business with DoD because they consider the government to be a bad customer. Some commercial firms cite excessive regulation, burdensome auditing and reporting requirements, damaging competitive procurement practices, rigid military specifications, compromise of proprietary information, loss of data rights, and corporate "culture shock" as reasons not to seek DoD business. Some of these problems might be resolved through DoD or congressional action. Others are probably inherent in any industry-government relationship.

5. The recent expansion of special access or "black" programs reflects both an effort to increase technological security and an attempt to circumvent burdensome regulation and congressional oversight. Because they are highly classified, such programs present additional barriers to companies that are not ordinarily engaged in defense work.

Findings Relevant to the Defense Industrial Sector

1. In many high-technology areas, the defense industries no longer lead the commercial sector, and the disparity may be increasing.

2. The defense industrial sector has been shaped by an ad hoc—yet extensive—system of regulation and defense industrial policies that has tended to stifle innovation and creativity over time. These include nearly 400 different regulatory requirements in the FAR alone, extreme and uncoordinated government auditing activity, and pervasive over-specification of developmental items. Some were established pursuant to acts of Congress; others are the result of internal DoD practices.

3. Congressional attempts to reform DoD and the defense industries may be inappropriately aimed at fixing an archaic military-industrial structure that is out of step with a world economy radically transformed by intense international competition. Comprehensive restructuring and elimination of inefficient elements and practices within DoD may be necessary.

4. Strategic planning in the largest defense prime contractors is based on the assumption that doing business with the government is a slow and ponderous process, and that it is not likely to get better. For better or worse, corporate planning is married to the DoD planning and budgeting cycle.

Findings Relevant to Congress

1. Congress plays a major role in shaping the acquisition process, and with it, DoD's access to both the defense-specific and commercial technology bases. But the acquisition system has built up over time, and overriding national goals often conflict with the particular program-specific objectives of defense acquisition. These national goals include efforts to ensure fairness, access for small and minority firms, environmental protection, competition, and the best product obtainable with the taxpayers' money.

2. The opportunity to interpret and amplify the intent of Congress exists at many levels—in OSD, in the Services, in the large prime contractors, and at the sub-tiers—and is often acted on, particularly where criminal sanctions might be imposed. The

result is a risk-averse, highly conservative defense industrial sector that has trouble taking advantage of rapid technological change in the commercial sector.

3. The structure of the large defense companies complements the legal, administrative, and bureaucratic form of the government. Such structures are imposed on the defense firms by acts of Congress, by DoD regulations, by military specifications, and by auditing requirements. Every aspect of business in these companies conforms to and is enforced by such bureaucratic and administrative controls. Making the defense industries more efficient and accountable might entail radical alteration of the legal and institutional structures that shape the DoD.

Findings Relevant to Civilian Industry

1. In many dual-use, high-technology industries, the civilian sector leads the defense industries. This civilian capacity may or may not be located in the United States.

2. A company can organize to do business in either the military or in the civilian sector of a high-technology industry, but it is extremely difficult to do both under one administrative roof. Companies that work in both sectors typically have separate divisions that are organized, administered, and staffed differently. In that case, the two divisions usually cannot share staff, production lines, laboratory facilities, data, research, accounting procedures, and other administrative systems.

3. These differences are profound. In large aerospace companies, for example, the commercial side of the firm responds to market conditions, whereas the military side of the house responds to the nature of the threat, to government directives, and to the federal budget. Executives and engineers transferred from a military to a commercial division often experience a prolonged period of culture shock and some are unable to make the adjustment. This is the opposite of the situation in civilian industry, where the chief executive officers of Fortune 500 companies are increasingly interchangeable.

4. Many entrepreneurial civilian companies—large and small alike—are unable and/or unwilling to conduct business with DoD because of the heavy investment and reorientation in business practices necessary to meet DoD requirements.

5. Antitrust policy and a rigid regulatory framework in some high-technology areas is adversely affecting the competitiveness of U.S. industry. Faced with foreign competition—specifically, with governments that act to create advantages for their firms in the U.S. market—U.S. firms may well fail to compete successfully with foreign businesses that are presently gaining experience in these areas.

POLICY CONSIDERATIONS FOR CONGRESS

The policy discussion that follows is divided into two areas. The first deals with the question of **military dependence on foreign civilian technology**. It is addressed because an increasing number of domestic high-technology industries that are important to the military are losing technology leadership and market share to foreign competition. The military response has been to buy materiel from high-technology firms located abroad. The second area focuses on the problem of **inadequate military access to civilian technology in the United States.** In many industries, the military could improve its access to civilian technology substantially, but Congress would have to make changes in the procurement system to stimulate DoD demand for civilian products and to make it easier for civilian companies to do business with DoD.

Military Dependence on Foreign Technology

The U.S. strategy of developing and fielding better military technology than that of potential adversaries requires that the DoD have access to many technologies that are sold primarily in civilian markets. The technologies of microelectronics, for example, and those contemplated for optoelectronics, require enormous and continuous investments in R&D and production facilities. These investments will be made only by companies that expect to sell the resulting products in a civilian market that is many times larger than defense purchases. That market is generally one that innovates more rapidly, because intense competition has compressed the product life cycle, forcing the incorporation of technological advances at the earliest possible date. In most cases, DoD cannot afford to pay the price associated with this kind of R&D and is unable to induce private industry to develop it with the promise of future orders. Therefore, if the Defense

Department wants to acquire state-of-the-art technologies in these fields, it must purchase them from companies that are producing for, and selling to, a large civilian market.

Although it may be very important to U.S. national security that the Defense Department have access to such technologies, DoD can do very little to influence the location, ownership, capitalization, and fundamental directions of the commercial technologies and industries that it needs. These are driven, instead, by domestic and international market forces, financial opportunity, and the trade and industrial policies of OECD and other producer nations. The corporate structure that prevails will ultimately be determined by fierce international competition for civilian markets and by the national trade policies of self-interested individual trading nations.

Two policy problems arise in this context. First, there are unmistakable signs that participation by U.S. companies in the high-technology sector of the international economy is weakening in important respects. Significant loss of capacity by U.S. companies in these dual-use industries could ultimately undermine our basic military strategy of countering superior numbers of enemy troops and equipment with superior technology. The second problem, which follows from the first, is that DoD is becoming increasingly dependent on advanced technology and products that are developed abroad or by foreign-owned companies located in the United States. Although DoD does not maintain systematic records on the amount of foreign content in U.S. weapons systems, military and civilian officials agree that it is significant and growing. Failure to address these problems would eventually leave the U.S military vulnerable to the self-interested actions of other nations upon whose technology the U.S. may depend.

There are no easy solutions. DoD is a small and relatively insignificant customer when compared to aggregate consumer demand in most high-technology, civilian-based industries. Accordingly, a requirement that DoD systems contain products made only by U.S.-owned companies located in the United States would exert little influence on the international marketplace. Instead, such a mandate would be likely to produce a number of unintended and dangerous consequences. It would, for example, limit access to advanced foreign technology, heighten tensions with our allies and trading partners, and create financial and administrative havoc in the defense sector of the U.S. economy. The resulting industries would have small, assured markets, and accordingly, little incentive to press toward the cutting edge of international technological competition.

If Congress wishes to address this problem, it will find that the issues of eroding dual-use industries and military dependence on foreign firms extend well beyond the purview of the DoD as well as the jurisdictions of the Armed Services committees of both Houses. This is because the environment in which policy must operate is the civilian sector of the international high-technology economy. DoD does not have the competence, the resources, or the policy levers to approach the situation in a comprehensive manner. At best, it can attempt band-aid solutions, such as funding Sematech and research into high definition television. What DoD might usefully do is to help establish parameters for the kinds of dependence that would be more or less acceptable, even if it cannot take meaningful steps to address the underlying causes of foreign dependence. Similarly, the Armed Services committees are constrained by custom and by the limits of their jurisdictions. As a result, few if any policy choices are available without the cooperation of the tax and trade policy committees which most affect the rules by which companies compete in America. Nevertheless, the nation and the Congress have a national security interest at stake, because it is unlikely that DoD, acting alone, will be able to keep pace with worldwide technological developments and avoid foreign dependence.

Policymakers will have to start with a clear conception of what a U.S. corporation or industry is, and will have to distinguish between the question of ownership and that of location of manufacturing facilities. Figure 10 indicates four different combinations, each of which suggests the need for a different policy response. In case 1, the simplest case, a corporation or industry is largely owned by U.S. interests and conducts most of its R&D and manufacturing operations in the United States. From a military perspective, this is the ideal situation, and it was, in fact, a characteristic condition in the immediate post-WWII era. At the other extreme, case 4, a corporation or industry is owned by foreign interests and is physically located abroad. Here, a flexible policy is needed that can calibrate the degrees of risk associated both with different supplier nations and with specific technologies of military significance. It would, of course, be necessary to make adjustments as international trading and military relationships evolve.

Cases 2 and 3 suggest intermediate possibilities. From a military perspective, case 2 (U.S.-based and foreign-owned) generally represents the more acceptable condition, because the corporation and most of its employees would be subject to the laws of the United States and could be required to give priority to U.S. national security needs in a crisis. But from an economic perspective, creating incentives for foreign-owned companies to locate manufacturing and R&D facilities in the United States might enhance or detract from the competitiveness of U.S.-owned companies with plants in foreign nations. There are competing interests at stake in these situations, but it is not necessarily a zero-sum game.

It is necessary, moreover, to distinguish between companies that merely assemble parts into finished products and those that actually conduct R&D and manufacturing operations in the United States. The former contribute far less to the U.S. defense technology base. In addition, DoD may need access to R&D and manufacturing facilities. While many analysts contend that the most efficient businesses colocate R&D and production facilities, the two are quite clearly separable. For example, Honda makes and sells cars in the United States but conducts research in Japan. And Corning Glass Works manufactures optical fiber in Australia but designs it in the United States. It would be important to consider that foreign-owned firms might produce less advanced technologies in the United States, saving the leading-edge R&D and production for their home bases. Care would have to be taken in connection with any policy that seeks to encourage foreign-owned firms to establish R&D and production facilities in the United States.

To the extent feasible, DoD would naturally prefer to minimize foreign dependence in dual-use industries that are important to the military (as in case 1). However, doing so is not a simple matter; it would require a variety of congressional actions, the consequences of which would extend far beyond their impact on foreign dependence for defense technology. Therefore, Congress will want to take many economic security considerations into account in considering whether or how to act.

The basic strategy for minimizing military dependence on foreign technology would be to extend a variety of incentives to U.S. companies to carry out R&D and manufacturing in the United States. A second, and perhaps complementary, course would be to establish incentives and sanctions to encourage foreign (and U.S.) companies to locate their R&D and manufacturing facilities in the continental United States (case 2). In high-technology industries where these two approaches might be unavailable, a realistic policy would rank technologies (according to military necessity) and countries (according to geopolitical factors). It would then be necessary to proceed on an industry-by-industry basis, weighing the risks of foreign dependence against the cost and feasibility of maintaining a particular capability in the United States. A policy framework for each of the four cases is shown in figure 10.

Case 1: If the goal is to promote military security, then it makes sense to establish policies to enhance the dual-use portion of the defense technology base that is U.S.-owned and located in the United States. The question of foreign dependence arises when a critical industry is failing in the United States or when U.S. companies fail to enter the competition in a particular technology at all. The policy problem is how to stimulate and otherwise assist corporations that produce technologies and products that are (or could be) important to the U.S. military. Policies that are intended to improve the defense capacity of these largely civilian companies may simultaneously affect their economic competitiveness. What is good for the military may or may not contribute to the health of any particular dual-use industry. It may be necessary to set up one group of institutional mechanisms to assist U.S. dual-use corporations and another to enhance military access to, and procurement of, technology and products developed in the civilian sector of the economy. These mechanisms are discussed at the end of this chapter.

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Figure 10—Military Dependence on Foreign Industry Ownership v. Location

LOCATION OF MANUFACTURING/ R&D CAPACITY	OWNERSHIP: U.S.	OWNERSHIP: Foreign
U.S.	1. Promotes military security	2. Acceptable, subject to U.S. priorities in a crisis
Foreign	3. Risk depends on specific technologies and nations	4. Least acceptable in terms of military security (#3 also applies)

SOURCE: Office of Technology Assessment, 1989.

Case 2: There will be some dual-use industries of military significance that are located in the United States, but which are partly or largely foreign-owned. The advanced composites industry is a good example. Roughly half of these companies are foreign-owned, but their R&D and production facilities are mainly based in the United States. This critically important technology is enabling for many defense aerospace applications. DoD has tended not to discriminate among such companies on the basis of national ownership, and has not promoted a stronger U.S. presence in this industry. In most cases, it makes little difference to the military whether or not a corporation or industry is dominated by foreign interests—so long as the critical R&D capacity and production facilities are maintained at state-of-the-art in the United States. Yet, distinctions would be necessary. For example, would it be acceptable for a company to manufacture products in the United States if all the machinery used in the plant were foreign-built? Similarly, in complex weapons systems, how far down the parts-supplier chain should a requirement to manufacture in the U.S. reach?

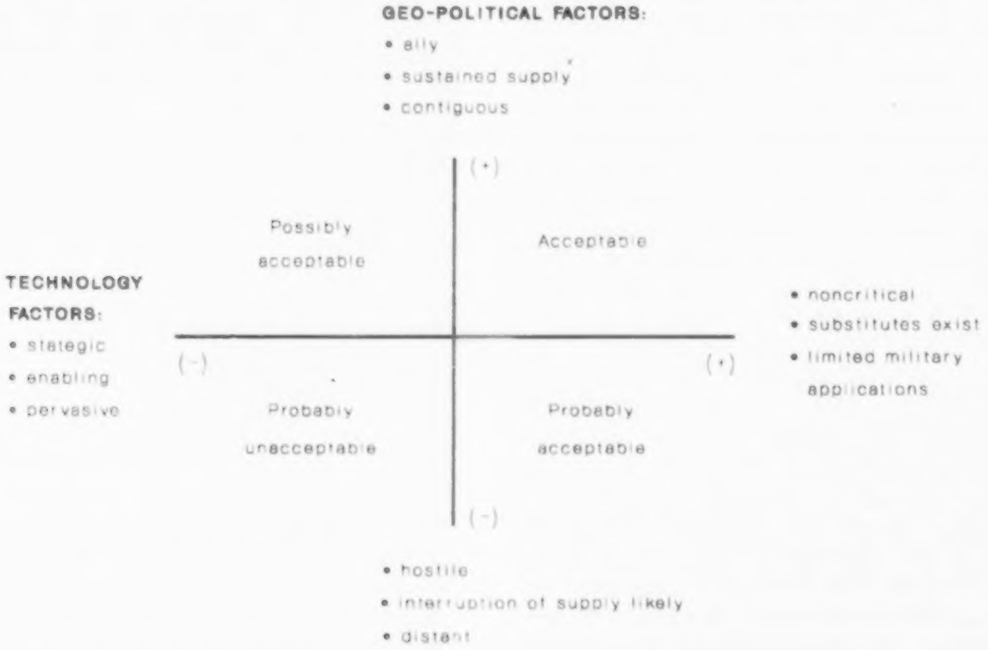
Case 3: Cases 3 and 4 can be combined, with the caveat that case 3 companies (those that are U.S.-owned and foreign-located) would presumably be more receptive to making concessions in the national interest, although still subject to host country controls on their operations. In general, these companies do not contribute significantly to the domestic defense technology base (although profits, if repatriated, may produce economic benefits for the United States). However, some U.S. companies conduct R&D in the United States, but have manufacturing and assembly operations overseas. Policy should be sensitive to this situation, acknowledging that these companies do make a contribution to the U.S. technology base beyond that of case 4 and some case 2 companies. Policy may seek to remove barriers that impede competitive domestic manufacturing.

Case 4: The defense implications of dependence on industries that are foreign-based and foreign-owned are more complex. Policy will have to be sensitive both to the geopolitical relationship between the United States and the particular foreign nation and to the specific technologies under consideration. Although it is an oversimplification, figure 11 displays some of the factors that would have to be evaluated on a case by case basis. The United States might, for example, tolerate foreign dependence for some key technologies and products if they were made in Canada, which shares technology base and free trade agreements with the United States. Contrast this with an extreme case, in which the U.S. military depends on a Warsaw Pact nation for a technology that is enabling for a major weapons system. While it is easy to discriminate between friendly neighboring countries and some Eastern European states, it is a matter of extreme delicacy to assess the security risk associated with technological dependence on a variety of nations, ranging from the EC to the Persian Gulf and the Pacific Rim. There is the further consideration that, for some technologies, the United States might be forced to accept a foreign supplier or do without. One alternative is to create the capacity domestically, using grants, tax incentives, guaranteed low-interest loans, R&D contracts with the government, and other schemes—possibly, but not necessarily, at expense to the taxpayer. There are also models from other nations, including Japan, where a portion of some domestic markets, both civilian and defense, is reserved for domestic firms.

Congressional Action and Institutional Mechanisms

Some analysts believe that new institutions will be needed to address these problems. They think it unlikely that Congress can effect such policies by delegating the task of implementation to existing agencies; no agency presently has the necessary capacities or powers. From this perspective, if Congress is interested in pursuing a policy on dual-use technology and foreign dependence, it could invest extraordinary powers and independence of action in a high-level council or agency created for that purpose. Such an agency would take steps to: 1) gather data on such essential items as foreign content in defense systems and foreign investment in high-technology companies, 2) assist U.S. dual-use industries that are essential to U.S. military security,

Figure 11—Military Dependence on Foreign Technology Located in Foreign Countries


GEO-POLITICAL FACTORS:
• ally
• sustained supply
• contiguous
(+)
Possibly acceptable
Acceptable
TECHNOLOGY FACTORS:
• stategic
• enabling
• pervasive
(−)
(+)
• noncritical
• substitutes exist
• limited military applications
Probably unacceptable
Probably acceptable
(−)
• hostile
• interruption of supply likely
• distant

SOURCE: Office of Technology Assessment, 1989.

3) induce foreign-owned companies that are located in the United States to conduct R&D and manufacturing operations here as well, and 4) develop or attract an indigenous capacity for dual-use technologies in industries where foreign dependence is unacceptable, and the domestic private sector is unwilling or unable to withstand or enter the competition.

As an alternative, Congress may wish to consider mandating coordination between existing agencies and offices such as the Department of Commerce, DoD, and the United States Trade Representative. There can be no assurance that such an approach would work. Each agency has its own established areas of business and expertise, and debilitating battles over leadership, functions, and turf could be expected. Congress might, of course, opt to require further studies of this problem and various approaches to it.

If Congress decides that an institutional approach to this policy area is inadequate, an array of strategies, used by other nations with varying degrees of success, is available. These include incentives and sanctions, both positive and negative. For example, Congress could require foreign-owned companies to locate manufacturing and R&D capacities in the United States if they intend to sell dual-use, high-technology products in this country. In addition, Congress could substantially strengthen the U.S. defense technology base through increased funding of graduate education for scientists and engineers, and by targeting the funds for American citizens, who are more likely to make their careers in the United States. Congress might require a policy of reciprocal dependence--for example, the United States might depend on Japan for DRAMs[16] and in return, Japan would agree to depend on the United States for jet engines, with the intent of establishing a regime of equivalent dependencies. Or Congress could change the structure of the tax system to encourage U.S. companies to make longer term investments, and change the tax code so that it no longer favors speculative investment by increasing taxes on short-term capital gains.

These options require painstaking analysis that is beyond the scope of this particular assessment. They are raised here because they illustrate the point that the solutions to the problems of eroding high-technology capacity and increasing military dependence, while critical to the national defense, fall outside the usual jurisdictions of the requesting committees of Congress. If the Armed Services committees believe that there is a national security interest in conserving the health of the defense technology base in the United States, it may be necessary to reorient the way in which the business of the committees is conducted—i.e., to focus less on the internal structure of DoD and more on taking steps to build a consensus within the Congress that can place these problems centrally on the national agenda.

Institutional and Administrative Barriers

Unlike the problems discussed above, the issue of military access to domestic technology falls squarely within the purview of DoD and the jurisdictions of the Armed Services committees of Congress. DoD and the military-industrial sector have become insulated from the rest of the economy in ways that tend to weaken military access to leading-edge civilian technology. This is largely the result of a gradual accretion of regulations, auditing requirements, paperwork, detailed specifications, and inefficient business practices that constitute substantial barriers between the military and civilian sectors of the U.S. economy. Most of these rules were instituted for good reasons and in response to real problems. But the cumulative effect has been to make defense procurement cumbersome and to concentrate military buying in a relatively small group of companies that have learned to conduct business according to government rules and norms.

If Congress wishes to improve military access to civilian technology, it will have to make some extremely difficult choices. Congress has played an integral role in establishing the structure of the military-industrial sector, as well as the rules and regulations under which it is run. To a large extent, Congress already approves or disapproves many important decisions that affect the defense technology base in the United States. The problem is that many isolated decisions and actions—taken not only by Congress, but also by DoD and the executive branch—have built up over time, and the resulting system is a patchwork of conflicting requirements and goals. To remove barriers that impede military access to the civilian sector, Congress will have to balance competing interests—many of which are supported by basic notions of fairness and other values that have shaped the present system. The most important barriers are outlined below, together with discussion of the relevant policy choices and problems.

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[16] Dynamic random-access memory chips.

Procurement Reform

In recent months, interest in the defense procurement process has focused on allegations of criminal activities by officials in the Pentagon and among some of the large defense prime contractors. While it is important to discourage such misconduct, an exclusive focus by the 101st Congress on issues of malfeasance will do little to address underlying structural problems that inhibit DoD's access to advanced civilian technology. Indeed, if Congress mandates several new layers of regulation and auditing in response, it may inadvertently create additional barriers.

Many civil-sector companies are already reluctant to bid on contracts with DoD because they are not organized and staffed to comply with the FAR, and because they do not need government business. Generally speaking, DoD has structured its procurement process to deal with corporations that are primarily or exclusively engaged in work for the military. These regulations inhibit access to companies whose technology and business is largely resident in the civilian sector of the economy. One result is that DoD is often forced to pay a premium for the development of a range of technologies and products that already exist in the civilian sector.

If Congress acts to increase regulation and auditing requirements, it may be able to reduce the amount of fraud and misconduct within the procurement system. But in so doing, it will almost certainly also reduce the efficiency of existing defense companies, because they will have to increase their paperwork load and internal audits to meet the new requirements. At the same time, tightening up the system to eliminate malfeasance would result in an even more complex regulatory environment for civilian firms, increasing the probability that such firms would not choose to work with the government in the future. One alternative is to do nothing, which is a possibility when combined with rigorous enforcement of criminal statutes already on the books.

The opposite course is also a viable policy option. Congress could take steps to reduce paperwork, regulation, and auditing, with the intention of increasing overall efficiency and DoD's access to high-technology companies and products in the civilian sector of the economy. Such action might or might not result in an increase of fraud and mismanagement in the defense sector. But it might expand the interaction with civil-sector firms that are now reluctant to do business with DoD. Some argue that the complexity of the defense regulatory environment encourages defense contractors to find ways to skirt the rules, simply because the proliferation of such regulations over time has made it extremely difficult to conduct business in an efficient and rational manner. Congress will have to sort out these issues as it seeks a policy that discourages misconduct without increasing the barriers of inefficiency and complexity that afflict the present system.

If Congress is reluctant to act, it may wish to study these problems in greater depth. To do so it could **establish an independent commission to explore the effects of: 1) reducing or expanding procurement regulations, and 2) exempting high-technology civil-sector firms from some procurement regulations**. This commission would examine the difficulties that civilian companies face in doing business with DoD. It would evaluate the ways in which the procurement system itself mitigates against military access to civil-sector technology. And it would weigh the costs and benefits of expanding or reducing procurement regulation. A central purpose would be to recommend changes in the procurement system that would induce civil-sector companies to sell their products to DoD or to modify them to meet DoD's needs.

A complementary and probably subsequent approach would be to create a market for civilian products in DoD by **mandating a preference for commercial items that are not developed under contract with DoD, using simplified and expedited contracting and acquisition procedures**. In DoD, commercial products are referred to as non-developmental items (NDI) and commercial off-the-shelf. The purpose of this preference would be to ensure that program managers give careful consideration to existing NDI/COTS technology before beginning new development. Despite repeated cabinet-level memoranda and executive direction to the contrary, DoD rarely substitutes commercial products for milspec developmental items. This is due partly to a historical bias in favor of contracting for development, partly to a reluctance of program managers to risk using items not designed to military specification, and partly to the regulatory structure that governs the procurement process. If Congress decides to increase government access to civilian-based technology and products, it will have to use the blunt instrument of a direct and unambiguous legislative mandate to overcome a large measure of resistance within DoD and the military sector of the economy.

It is likely that any reform of the procurement process that encourages the use of civil-sector technology and products will also require fundamental changes in the relationship between DoD and some of the firms with which it does business. Civilian sector executives who do not need DoD business are unlikely to tolerate the heavy hand of government regulators and auditors changing the administrative policies and practices of their companies. Regulated profits, detailed military specifications, set-asides for small and minority firms, affirmative action, specialized auditing procedures, and competitive bids from sub-tier suppliers may satisfy government notions of fairness and social responsibility. But when they are imposed on commercial operations, they tend to weaken the efficiency and competitiveness of companies that depend on sales in consumer markets for survival. These companies are in business to make a profit. Their managements are responsible to stockholders, who expect shorter-term results than are typically envisioned by government programs or international competitors. Congress will have to make allowances for the fundamental differences in the way business is conducted in the defense and civilian sectors of the economy, if it wants to increase military access to advanced, commercially based technologies and products.

Specifications Overhaul

In general, the DoD specifications process is too cumbersome and too rigid to establish reasonable and realistic standards for technologies that are changing rapidly. Too often, prescriptive standards are mandated where performance specifications would be more appropriate. Although they are necessary if DoD is to conduct procurement at all, specifications can lock the military into a developmental mode and block access to existing civil-sector technologies, products, and systems. The OTA case studies found instances where the military could not use existing superior civilian technology because DoD regulations mandated compliance with outmoded specifications. Civil-sector companies, military prime contractors, and milspec specialists in the Services all agree that there are too many specifications, referencing too many additional documents, and that there is no effective process for eliminating outdated and unnecessary documentation. Military specifications can exert the largely unintended effect of creating divergence between military and civilian applications of the same technologies.

If Congress wishes to address this problem, there are a number of steps it could consider. In high-technology fields where civilian products and technologies are clearly at the leading edge, **Congress could require the harmonization of military specifications with best practice in the civilian, high-technology sector**. Such a requirement would apply to dual-use technologies where meeting adverse training and battlefield conditions is not at issue. In its study of fiber optics and software, for instance, OTA found numerous examples where the military could benefit from adopting best practice in fast-moving civilian technologies. Such action might encounter resistance from quarters within DoD where there is a strong belief in the necessity of designing systems specifically to meet user requirements and battlefield conditions. Nevertheless, where the underlying technologies are similar in the defense and civilian sectors, great cost savings might be realized by tailoring military specifications to take advantage of existing civilian products and applications—as opposed to designing divergence into the specification and codifying it.

In addition, Congress may wish to **mandate the use of performance-type specifications in fast-moving, high-technology fields**. The alternative is to nail down prescriptive standards that tend to freeze military systems at or below present-day levels of technological development. Performance specifications have the advantage of introducing a measure of flexibility into the system itself, and into the procurement process, that could substantially enhance military access to advanced technologies in the civilian sector. They could be written broadly to encourage substitution of NDI or COTS products where possible.

It is unlikely that specific policy options can be implemented until the system of writing military specifications and the culture that sustains it are changed. With this caveat in mind, Congress might **require the review and consider the revision or nullification of existing prescriptive specifications at some specified interval**. The purpose of such a review would be to make the process of writing specifications more responsive to technological advances in the civilian sector, and to do away with the proliferation of unnecessary or outdated requirements and documentation. By the time they are written, many military specifications no longer reflect the state of the art in dual-use technology industries. This is partly because the product cycle is so much shorter in the civilian sector. In order to reduce the multiyear process of specification writing, it may be necessary to introduce greater flexibility by reducing inter-Service coordination and permitting the different Services to use different specifications to meet their specific needs.

Restructuring Data Rights

It is extremely difficult to strike an equitable and appropriate balance in allocating data rights in contracts between the government and the private sector. Government agents tend to demand as many data rights as they can get in any given contract because they are under a fiduciary obligation to protect the interests of the government. In many cases, the contractors lose most, if not all, of their intellectual property rights to the technology and products they develop. DoD negotiators typically demand the right to duplicate, use, and disseminate such data without restriction. The claim to unlimited data rights is based on three important considerations. The first is that by securing complete data rights, DoD is in a position to foster competition by sharing the data among potential contractors. Second, unlimited rights protect the government from future costs and claims of infringement, and help to ensure dissemination of publicly sponsored research efforts. And third, full data rights to software ensure that DoD will be able to modify and maintain software in the field.

This orientation contrasts sharply with practice in the civilian sector, where R&D and process data are carefully guarded and no company could expect any rights to another's proprietary information. Many executives of civil-sector firms believe that government procurement officers and regulations do not recognize the extent to which high-technology industries are driven by R&D activity. These firms are typically unwilling to share data, because they believe it can be used to reveal a core of proprietary information. In some cases, software and fiber optics companies invest tens of millions of dollars to develop a process or series of products. Consequently, these civil-sector companies are unwilling to contract with DoD, because it insists on extensive data rights and may even set a competitor up in business.

In the case of software, the most recent directives and regulations enable DoD to accept limited rights to intellectual property. For software developed wholly with private funds, the contractor can negotiate restricted data rights giving the government the ability to modify software and make backup copies, but allowing the developer to incorporate a typical licensing agreement. The government hopes to retain the ability to maintain its software systems and to ensure that future maintenance and reprocurements will be competitive. Despite these acknowledgments and the flexibility granted government contracting officers to negotiate less-than-exclusive rights to data, DoD still insists on full transfer of data rights in most cases.

If Congress wants to increase government access to civilian high-technology firms, it will have to reevaluate the principle of exclusive and unlimited data rights. In part, this may require that DoD distinguish companies that have developed a product or process with private funds from those that have done so under contract with the government or with funds that are reimbursed by DoD. In addition, Congress might require DoD to create different categories of data rights—ranging from the unlimited to the narrowly specified—when it is buying from firms that do most of their business in the private sector. Congress may wish to review existing data rights policies and procedures mandated internally by DoD directives, and to assess the level of training that would be necessary to enable contracting officers to negotiate data rights and still protect the legitimate interests of the government.

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